

N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE

Support Services for the Automotive Gas Turbine Project

Summary Report

(NASA-CR-165331) SUPPORT SERVICES FOR THE
AUTOMATIVE GAS TURBINE PROJECT Summary
Report (Chrysler Corp.) 148 p HC A07/MF A01
CSCL 13F

N81-25875

Unclas
G3/85 26585

Edited by
T. Golec
Chrysler Corporation
Detroit, Michigan 48288

April, 1981

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135
Under Contract DEN3-144

for
U. S. Department of Energy
Office of Conservation and Solar Applications
Division of Transportation Energy Conservation
Washington, D. C. 20545



NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agent, the United States Department of Energy, nor any Federal employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Support Services for the Automotive Gas Turbine Project

Summary Report

Edited by

T. Golec

Chrysler Corporation

Detroit, Michigan 48288

April, 1981

Prepared for

National Aeronautics and Space Administration

Lewis Research Center

Cleveland, Ohio 44135

Under Contract DEN3-144

for

U. S. Department of Energy

Office of Conservation and Solar Applications

Division of Transportation Energy Conservation

Washington, D. C. 20545

Under Interagency Agreement EC-77-A-31-1040

TABLE OF CONTENTS

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
	List of Illustrations	v
	Preface	1
1.0	Summary	1
2.0	Introduction	1
3.0	Engines (Retrofit, Test and Maintenance)	2
3.1	Engine 1 (PP3-13), Retrofit 1	2
3.2	Engine 2 (PP4-15), Retrofit 4	2
3.3	Engine 3 (PP2-16), Retrofit 5	3
3.4	Engine 4 (PP5-4), Non-Retrofit	4
3.5	Engine 5 (PP8-10), Non-Retrofit	5
3.6	Engine 6 (PP10-14), Retrofit 2	5
3.7	Engine 7 (PP9-11), Retrofit 3	5
3.8	Engine Design, Drawing, Parts List Update	6
3.9	Spare Engine Components	6
4.0	Vehicles	7
4.1	Maintenance	7
4.2	Demonstrations	8
4.3	Vehicle Usage	8
4.4	Vehicle Status	8
4.5	Baseline Vehicles	8
4.6	Upgraded Vehicles	8
5.0	Control Systems	10
5.1	Familiarization Session at NASA LeRC	10
5.2	Electronic Control Unit Modifications	10
5.3	Power Turbine Nozzle Vane Control	10
6.0	Development Testing	11
6.1	Variable Speed Rubber Belt Evaluation	11
6.2	Regenerator Core/Ring Gear Elastomer	11
7.0	Miscellaneous	13
7.1	Delivery of Parts	13
7.2	Inventory, DOE Government-Owned Capital Prop.	14
7.3	Parts Failure Reporting	14
8.0	Conclusions	14
9.0	Recommendations	15
	Figures	17ff
Appendix A	Specifications	A-1
Appendix B	Delivery Order Summary	B-1
Appendix C	Failure Reports	C-1

LIST OF ILLUSTRATIONS

<u>FIGURE</u>	<u>TITLE</u>
1.	Engine Status
2.	Probe Locations in Gas Generator
3.	Probe Orientation - Rotor Shaft Dynamics
4a.	Instrumentation for Shaft Dynamics
4b.	
5.	List of Special Instrumentation - Shaft Dynamics
6.	Rotor Shaft Dynamic Deflection
	Rotor Shaft Dynamic Tests -
7a.	- Start Cycle, Impeller
7b.	- " " Turbine
7c.	- " " Starter Dropout-Impeller
7d.	- " " Starter Dropout-Turbine
7e.	-Steady State 50%-Impeller
7f.	- " " 50%-Turbine
7g.	- " " 65%-Impeller
7h.	- " " 65%-Turbine
7i.	- " " 70%-Impeller
7k.	- " " 80%-Impeller
7l.	- " " 80%-Turbine
7m.	-Steady State 90%-Impeller
7n.	- " " 90%-Turbine
7o.	- " " 100%-Impeller
7p.	- " " 100%-Turbine
	Engine 3, Failed Components
8a.	-Glazed Regenerator Core (Typical)
8b.	-Thrust Bearing
8c.	-Anti-thrust Bearing
8d.	-Thrust Plate
8e.	-Power Turbine Rotor Repairs
9.	Sketch, Power Turbine Wheel Salvage
10.	Engine 3 Performance
11.	Engine 3 Performance & Emissions
12.	Support to DOE - Service Calls
13.	Support to DOE - Summary of Exhibits, Displays, Demonstrations
14a.	Vehicle Usage Summary
14b.	

List of Illustrations, Continued

<u>FIGURE</u>	<u>TITLE</u>
15.	Baseline Vehicle Summary
16.	Upgraded Vehicle Summary
17.	Cold Start Diagnostic Chart - Vehicle U-2
18a.	Vehicle U-4, 1980 Dodge Mirada
18b.	Vehicle U-4, 1980 Dodge Mirada Engine Installation
19a.	Outline, Control System Familiarization Session
19b.	
20.	Power Turbine Nozzle Vane Mechanism Rub Block Modification
21.	Belt Drive CVT Test Rig
22.	Belt Drive Test Points
23a.	Belt Drive Characterization
23b.	" " "
23c.	" " "
23d.	" " "
23e.	" " "
23f.	" " "
23g.	" " "
24.	Elastomer Sample Shear Test Fixture
25.	Elastomer Samples Before and After Test
26.	Elastomer Sample Shear Test Fixture - Elevated Temperatures
27.	Elastomer Test Results, Elevated Temperatures
28.	Advanced Ring Gear/Core Elastomer Design
29.	Effect of Moisture on Seal/Matrix Torque
30.	Delivery of Parts to NASA LeRC
31a.	Procurement Summary
31b.	

PREFACE

This Service Contract, DEN 3-144, was issued October 17, 1979 by the NASA Lewis Automotive Power Systems Office as part of their overall project responsibility for the DOE automotive heat engine programs. Its purpose was to support continued use by the Government of Baseline engines and vehicles and Upgraded engines and vehicles delivered by Chrysler to the Government under DOE Contract EY-76-C-02-2749.

The scope of work to be performed as defined in the Specifications section of the contract is included in Appendix A. Specific tasks to be performed under these specifications were defined by twenty-one delivery order requests from the NASA Project Officer, Appendix B.

1.0 SUMMARY

Seven delivery orders were carried out in the area of gas turbine exhibits and vehicle demonstrations. These were to support DOE and NASA in their efforts to inform industry, the public, and Government on the benefits and purpose of the gas turbine programs.

Three delivery orders were carried out which involved limited testing to evaluate components, also under the task of providing information which demonstrates the potential of the gas turbine engine. Data were generated on air bearing rotor shaft dynamics, heavy duty variable sheave rubber V-belts, high temperature elastomer regenerator drive mounting and graphite regenerator seal friction characteristics.

Nine delivery orders were carried out for maintenance, repair, and retrofit of the experimental gas turbine engines being used by NASA in their gas turbine technology programs and in program demonstrations. Spare parts were procured and/or provided as necessary. Prints and parts lists of engine design updates and microfilms were delivered to the program.

Two delivery orders were carried out in meeting the report requirements.

2.0 INTRODUCTION

During the test and development period of the Upgraded Engine and Vehicle Program commencing in July, 1976, a total of seven engines were built. Five engines were retrofitted; the last, Engine 3, retrofit 5, was funded by this contract. The status of the engines and their location at the termination of the service contract, January, 1981, are summarized in Figure 1. Three engines were tested in vehicles, designated U-1, U-2, U-3, and an update, U-4. Three were assigned to the ongoing development activity at NASA LeRC in Cleveland, Ohio. The remaining engine was used for providing experimental information for the AGT102 program at the Chrysler Facility in Detroit.

At the time this report was being written all three vehicles were in the Chrysler laboratory, but two vehicles, U-2 and U-4, were imminently assigned to DOE headquarters in Washington, D.C.

For clarity of presentation, the following reporting is by subject area, in that individual delivery orders overlapped subject engine, vehicle and test activity.

3.0 ENGINES (RETROFIT, TEST AND MAINTENANCE)

3.1 Engine 1 (PP3-13), Retrofit 1, w/Noel Penny Power Stage, Chrysler Test Facility

This engine was principally used to document gas generator rotor shaft dynamics during start conditions, steady-state, accel, decel and shut down at several lubricant temperatures. The latest mod air bearing, improved spot welded foil utilizing fine grain X750 material, was installed.

The gas generator was instrumented with two pair of probes, front and rear, as shown in Figure 2, to define shaft movements. It was not feasible to calibrate the probe system to determine the temperature effect on the output signal. Therefore, the surfaces beneath the probes were interrupted with grooves of two different depths (blips). These grooves act as calibration marks to determine both shaft deflection amplitudes and shaft orientation. The groove detail is shown in Figure 3.

Regulated shop air was required to force-cool the rear hot probes during both running and soakback phases.

Figures 4a and 4b define the instrumentation setup and Figure 5 lists this special equipment. The use of an oscilloscope with camera and visicorder allowed quick-look data capabilities to identify any gross anomalies during the test.

Figure 6 shows the deflection amplitudes for both the cold (front) and hot (rear) locations. These data are from initial tests before the FM tape recording outputs were available.

FM tape recording results are shown in Figure 7a through 7p for steady-states and starts only. These data indicate relatively large deflections for speeds up to 70%. Additional reduction of the tapes was terminated due to lack of funds.

The original plan was to document rotor shaft dynamics at minimum unbalance with the unbalance forces coplanar in the same direction. The data would be analyzed by NASA, MTI and Chrysler personnel. Subsequent tests, dependent on the analysis, would include coplanar forces in the opposite direction, increased imbalance and possible use of a compliant shaft seal replacing the control gap seal. Funding limitations did not permit this plan to ensue.

3.2 Engine 2 (PP4-15), Retrofit 4, Vehicle U-4

This engine was first retrofitted in October, 1978 and installed in vehicle U-1 until June, 1980. Prior to installation in U-4 (Dodge Mirada) the engine was disassembled to install a new impeller and inspect the reduction gears.

The power turbine wheel had rubbed the outer shroud. Inspection showed the bulkhead to be distorted and not concentric to the power turbine/gas generator pilots. The engine housing and power turbine nozzle assembly were machined, reestablishing the respective pilots. A new power turbine wheel and reduction gear set were used for this build.

The first stage turbine wheel was replaced as it had crack indications at the blade root; area see Appendix C (Failure Report 84). This wheel was one of the first Mod 3 castings.

The latest 18/18 bladed, steel inducer impeller was also included in this build as these components have better performance than the 24 bladed version.

The engine was run briefly on the dynamometer to check mechanical integrity and spot check power which was 64 hp @ 95%.

3.3 Engine 3 (PP2-16), Retrofit 5, NASA LeRC

Power Plant 2-3 was returned to Chrysler in May, 1979 for retrofit to the A926-1 configuration, and re-designation as PP 2-16. Total engine time was 359.4 hours. On teardown a number of discrepancies were found, including a glazed regenerator core, failed power turbine thrust bearing, and heavily rubbed PT rotor. These findings are documented in Appendix C (Failure Report No. 74) and related photographs, see Figures 8a through 8c.

Following thorough cleaning and inspection, the -1 retrofit was performed. This consisted of updating the gas generator to the Mod 3 configuration, the power turbine nozzle assembly to Mod 2, and the power turbine assembly to Mod 2. During the rebuild, a number of deviations from the released A926-1 parts list were required, as follows:

- The air inlet was re-instrumented, and the inlet guide vanes reworked to assure capability of setting +60° throttling position if required. Program constraints prevented fitting the engine with a two-position VIGV actuator as planned; the engine was shipped with the VIGVs locked at zero degrees.
- A new 18-18 splitter impeller with steel inducer was installed to facilitate rotor speed instrumentation requirements. The gap between inducer and impeller was not filled. Clearances were higher than desired - 0.012 in. radial and 0.015 in. axial.
- As requested, a lean, premixed, prevaporized (LPP) combustor was installed. To adapt this assembly to the Mod 3 vortex, the combustor tube required modification per sketch 952-SK-23187.
- A full set of flow baffles were installed in the engine housing per drawing 4096591.
- The elastomer flow dam was installed in the regenerator cover for improved flow distribution. This dam is defined on drawing 3814278, revision "J".

- A regenerator core of AS material had been requested. However, because of the limited availability of AS cores, the engine was delivered with a standard IAS core.

- The regenerator static "L" seals were serviced and replaced as required. Final engine cold leakage was 6.1% at 80% Ngg conditions, slightly above the normal limit of 6%. Time did not permit investigation of the leakage.

- Because no new parts were on hand, air bearing S/N 21-1 was inspected and re-installed in the engine. Previous running time on this part was 19.9 hours in PP2-3 build B0.

- Similarly, power turbine wheel S/N 202, found damaged on teardown, was the only available part. The heavily rubbed areas at the blade leading edge tip and root were machined to a smooth contour as shown on Figure 9, and the wheel re-inspected and judged acceptable for reinstallation as a limited-service part. PTW tip clearance was set at 0.012 in. minimum, based on previous experience with light PT tip rubs when 0.010 in. clearance was used.

- As requested, instrumentation was limited - standard instrumentation such as P_2 statics and P_5 total probe were omitted.

- It was originally planned to include, as part of the retrofit, a set of specially-contoured PTN shrouds as supplied by NASA. However, due to an interference problem with these new shrouds, it was agreed to build the engine with standard Mod 2 PTN parts.

Shakedown testing revealed no mechanical problems, and performance was satisfactory at 79.3 HP. Figures 10 and 11 compare PP2-16's performance to the original A-926 design goals. The lower-than-expected performance was attributed to the high compressor clearances, salvaged PT wheel, and excessive seal leakage, as discussed above. However, it should be noted that, prior to retrofit, this engine only produced 53.6 HP (PP2-3 BK).

A combustor problem early in the test period was resolved by increasing burner dilution area by 20%; final NOx emissions values are shown on Figure 11. A speed stability problem above 80% Ngg was traced to a design deficiency in the ECU. Documentation of corrective action is shown in Appendix C (Failure Report 82).

Following a total of 28.7 hours of shakedown testing and calibration, the engine was prepared for shipment, and delivered to NASA on March 24, 1980.

On January 8, 1981 the gas generator was disassembled at NASA to investigate the cause of high rotor drag, and the smooth foil of air bearing S/N 21-1 was found shifted forward. Subsequent inspection of the bearing at Chrysler is documented in Appendix C (Failure Report 92).

3.4 Engine 4 (PP 5-4), Non-Retrofit, NASA LeRC

This original release engine, extensively instrumented at NASA LeRC, was tested at NASA to document Upgraded engine performance levels.

In an effort to determine the cause of reported high blowby, power turbine/reduction gear 4 was returned to Detroit for inspection. Seal leakage measurements were documented and were within acceptable limits. The unit was returned to LeRC.

Engine 4 was deactivated, removed from cell SE-2 and replaced with a retrofitted engine.

3.5 Engine 5 (PP8-10), Non-Retrofit, Vehicle U-3

This engine was installed in vehicle U-3 in September, 1977 and was principally used for display purposes. Engine service was minimal. The combustor cover was replaced as the original had loose insulation. The original mixer/ignitor alignment was unacceptable, therefore a new mixer was installed; see Appendix C (Failure Report 89).

A short in the wiring circuit of the electromagnetic clutch required replacement of the clutch assembly; see Appendix C (Failure Report 88).

An original release air bearing, with molybdenum disulfide coating, has accumulated 1384 starts to date. Engine speed is limited to approximately 85% speed.

3.6 Engine 6 (PP10-14), Retrofit 2, Vehicle U-2

This engine was retrofitted and first evaluated in a test cell in July of 1978 and installed in Vehicle U-2 September, 1978. The engine was removed to replace a failed power turbine one month later. The replacement assembly utilized the latest modification, higher capacity thrust/anti-thrust bearing system.

The gas generator assembly was refurbished in December, 1979 to replace T_5 thermocouples that had deteriorated. Air bearing 8-2, which had accumulated 188 hours, 2195 miles, and 1104 starts, was replaced with an updated bearing, i.e., fine grain X750 foil with "improved" spot welding. Bearing 8-2 exhibited edge loading toward the turbine wheel side, and was delivered to NASA LeRC, and then to MTI, for inspection and commentary.

The replacement air bearing has accumulated 82 hours of test time, 1283 miles, and 557 starts to date without incident.

3.7 Engine 7 (PP 9-11), Retrofit 3, NASA LeRC

The engine is retrofitted with Noel Fenny second stage hardware and was first run in November, 1978 and delivered to NASA LeRC in May, 1979. Three regenerator elastomer drive failures occurred between December, 1979 and March, 1980 and are discussed in detail in Section 6.2.

The fuel metering valve was replaced with the valve from PP5-4 (inactive at LeRC). Reports of positive fuel shutoff problems prompted the change. There were no significant calibration differences to warrant reprogramming the ECU fuel schedule.

Erratic operation of the power turbine nozzle actuator prompted its return for repair in late September, 1980. The problem was traced to galling between the output rod and aluminum adaptor which had not been anodized as specified.

In an effort to determine the cause of reported high blowby, power turbine/reduction gear 4 was returned to Detroit for inspection. Seal leakage measurements were documented and were within acceptable limits. The unit was returned to LeRC.

Engine 4 was deactivated, removed from cell 3E-2 and replaced with a retrofitted engine.

3.5 Engine 5 (PP8-10), Non-Retrofit, Vehicle U-3

This engine was installed in vehicle U-3 in September, 1977 and was principally used for display purposes. Engine service was minimal. The combustor cover was replaced as the original had loose insulation. The original mixer/igniter alignment was unacceptable, therefore a new mixer was installed; see Appendix C (Failure Report 89).

A short in the wiring circuit of the electromagnetic clutch required replacement of the clutch assembly; see Appendix C (Failure Report 88).

An original release air bearing, with molybdenum disulfide coating, has accumulated 1384 starts to date. Engine speed is limited to approximately 85% speed.

3.6 Engine 6 (PP10-14), Retrofit 2, Vehicle U-2

This engine was retrofitted and first evaluated in a test cell in July of 1978 and installed in Vehicle U-2 September, 1978. The engine was removed to replace a failed power turbine one month later. The replacement assembly utilized the latest modification, higher capacity thrust/anti-thrust bearing system.

The gas generator assembly was refurbished in December, 1979 to replace T₅ thermocouples that had deteriorated. Air bearing 8-2, which had accumulated 188 hours, 2195 miles, and 1104 starts, was replaced with an updated bearing, i.e., fine grain X750 foil with "improved" spot welding. Bearing 8-2 exhibited edge loading toward the turbine wheel side, and was delivered to NASA LeRC, and then to MTI, for inspection and commentary.

The replacement air bearing has accumulated 82 hours of test time, 1283 miles, and 557 starts to date without incident.

3.7 Engine 7 (PP 9-11), Retrofit 3, NASA LeRC

The engine is retrofitted with Noel Penny second stage hardware and was first run in November, 1978 and delivered to NASA LeRC in May, 1979. Three regenerator elastomer drive failures occurred between December, 1979 and March, 1980 and are discussed in detail in Section 6.2.

The fuel metering valve was replaced with the valve from PP5-4 (inactive at LeRC). Reports of positive fuel shutoff problems prompted the change. There were no significant calibration differences to warrant reprogramming the ECU fuel schedule.

Erratic operation of the power turbine nozzle actuator prompted its return for repair in late September, 1980. The problem was traced to galling between the output rod and aluminum adaptor which had not been anodized as specified.

A service call was required in late October to familiarize NASA LeRC with installation and programming procedures for the replacement nozzle actuator. The original actuator was reconditioned, the adaptor anodized, and the assembly returned to NASA as a spare.

A gas generator air bearing failure in December required considerable support activity to prepare and provide the replacement parts; see Appendix C (Failure Report 91). NASA LeRC personnel will reassemble the gas generator at their facilities.

3.8 Engine Design, Drawing, Parts List Update

During the service contract period, drawings and parts lists were updated to reflect the ongoing engineering changes instituted by vendors, laboratory and design personnel. The Chrysler engine model number was changed from A926 to A926-1 and is represented by Parts List 724. Sub-assemblies such as the Noel Penny power turbine stage and droplet diffusion combustor were assigned to the optional parts list while the original power stage (with turbine wheel blades restaggered 6°) and lean, premixed, prevaporized combustor were retained on the -1 parts list.

Microfilms of the updated parts were prepared, mounted in NASA aperture cards, and delivered to LeRC.

Chrysler part numbers are cross indexed to the NASA numbering system. Originally NASA assigned P/N C(X)759243 through C(X)760242 to Chrysler for a total of 1000 numbers. To date numbers up to C(X)759962 were used leaving 281 numbers. Additionally C(X)643789 through C(X)644287, a total of 498, were assigned but not used.

Summarizing the status of the A926-1 upgraded engine release, the gas generator, combustor, regenerator and part of the engine housing are fully updated and included on the 724 parts list. Some minor revisions and/or corrections in the air intake, power turbine, vehicle accessories and parts of the engine housing were never completed due to lack of funds.

3.9 Spare Engine Components

In an effort to minimize engine and vehicle down time, spare gas generator and power turbine/reduction gear assemblies were built and include:

- Gas generator 4, non-retrofit for Engine 5, PP8-10, Vehicle U-3. Although a non-retrofit gas generator, this assembly is comprised of improved aerodynamic hardware, specifically CTN122 and 0.8 Baseline CTW 125. The air bearing represents the latest mod, i.e., fine grain X750 foil with improved spot welding. This unit was assembled as a replacement for the gas generator currently installed in the vehicle (assembled in July, 1977, original release aero hardware and air bearing).
- Gas generator 10, retrofit, minimum instrumentation, for vehicle use. This assembly has an 18/18 steel inducer impeller, CTN 157 (-1°), CTW 153, and latest mod air bearing.

- Power turbine/reduction gear 2, retrofit for vehicle use. This assembly is comprised of an 11° bent PTW 221, modified diffuser and rotor bearing configuration.
- Power turbine/reduction gear 9 retrofit, for test cell use only, Engines 1 and 7. This assembly utilizes the Noel Penny power stage and latest rotor bearing configuration.

4.0 VEHICLES

Vehicles were serviced and maintained to assist DOE in its efforts to inform the Government, industry and the public of the DOE Gas Turbine Highway Vehicle Systems Program. Vehicles were in service at DOE Headquarters in Washington, D.C. and at various DOE sponsored shows and exhibits throughout the country.

Two baseline and two upgraded vehicles were maintained and made available for ride/drive demonstrations for this task. One of the original upgraded vehicles, a 1976 Dodge Aspen, was replaced by a 1980 Dodge Mirada. Additionally, a restyled Chrysler LeBaron show vehicle was maintained and displayed.

The six vehicles involved in support of the Government are identified below.

Baseline	B-2	(Car 667)	1973	Plymouth	Satellite
"	B-3	(Car 671)	1973	"	"
Upgrade	U-1*	(Car 385)	1976	Dodge	Aspen
"	U-2	(Car 386)	1976	"	"
"	U-3	(Car 649)	1977	Chrysler	LeBaron
"	U-4	(Car 469)	1980	Dodge	Mirada

* Note: Vehicle U-4 replaced U-1 as an update.

4.1 Maintenance

Baseline vehicle B-3, assigned to DOE headquarters, Washington, D.C., was principally utilized for ride and drive demonstrations.

Two service calls were required to correct an "abort start" condition. The start cycle safety system (T_5 temperature rate of rise) failed and was attributed to excessive underhood temperatures. A radiation shield was installed to reduce heat input to the start cycle safety system. No system development was pursued. Combustor components and an alternator were replaced after routine maintenance.

Limited Upgraded vehicle usage at DOE Headquarters, Washington, D.C., exhibited cold start problems. The vehicle was returned to Detroit as suitable diagnostic equipment was not available. Figure 12 summarizes Baseline and Upgraded vehicle service calls.

4.2 Demonstrations

A chronological summary of exhibits, displays and demonstrations is shown in Figure 13. All requests for vehicle exhibits, displays, and demonstrations were met.

The vehicles were driven by numerous people with a minimum of familiarization required. Generally, driveability was reported as satisfactory and noise levels acceptable.

4.3 Vehicle Usage

Monthly operational summaries of the five vehicles active during this period are shown in Figures 14a and 14b.

4.4 Vehicle Status

Figures 15 and 16 summarize the specifications and status of the Baseline and Upgraded vehicles respectively.

4.5 Baseline Vehicles

B-2, 1973 Plymouth Satellite

Work was initiated to reactivate this vehicle after two years of storage. A gas generator change was required. The previous gas generator was damaged. Loss of oil pressure had failed the rotor bearing. The vehicle is almost operational.

B-3, 1973 Plymouth Satellite

This vehicle, assigned to DOE Headquarters, Washington, D.C., required minor service as discussed previously. The vehicle is presently in Detroit. It was replaced in Washington by Upgraded Vehicle U-2.

4.6 Upgraded Vehicles

U-1, 1976 Dodge Aspen

This vehicle was the second to be assembled for the program and is essentially identical to U-2. It was utilized to support ride and drive demonstrations for the coordination meetings in the Detroit area. Vehicle activity during this period was minimal. The car was deactivated and stored in June 1980. The engine was removed and inspected (Ref. Section 3.2) and transferred to the Dodge Mirada, U-4.

U-2, 1976 Dodge Aspen

This vehicle supported numerous Government-sponsored shows and exhibits around the country. As such, considerable commercial shipping was utilized which resulted in damage to the vehicle structure and suspension. Strengthening the problem areas reduced the severity of damage but did not eliminate the problem, see Appendix C (Failure Report 86). The

damage was considerably more severe than what is encountered in corporate show vehicles shipped around the country. The severity suggests abusive shipping procedures/tie-down techniques, e.g., rough roads and excessive tie-down loads. The shipping contractors were alerted to the problems and placed in direct contact with our corporate shipping personnel in an effort to eliminate the problem.

During ride/drive demonstrations at Ames and Council Bluffs, Iowa, the vehicle was driven a distance of 189 miles at approximately 60 MPH average speed. This included 24 miles of typical city driving. Average fuel economy (gasoline fuel) was 21.5 MPG, which agrees favorably with tests conducted on a chassis rolls that averaged 21.15 MPG.

The vehicle was placed in service at the Department of Energy, Washington, D.C. in late September, 1980, and remained in service for two months. Complaints of cycling, undershoot, and smoke were reported during the cold start procedure only. The vehicle was recalled and considerable time and effort were expended in an attempt to identify and resolve the problem. Interaction of the various systems and sub-systems which could contribute to the problem are shown in Figure 17. Current field service is very difficult without the necessary support diagnostics and readouts. The cold starting deficiency was traced to an intentional contamination of the fuel tank with kerosene-type fuel, see Appendix C (Failure Report 93). The upgraded combustor/control system has minimal development effort with alternate fuels. The effect of alternate fuels on the elastomers, e.g., o-rings, seals, etc., is of prime concern, as these may cause swelling, resulting in erratic and/or inoperative components.

U-3, 1977 Chrysler LeBaron

This is a modified 1977 LeBaron coupe with a distinctively-restyled fiberglass front end. This show vehicle was built at the request of the Department of Energy as a Public Interest Car (PIC). This vehicle's use is to focus interest and attention to the gas turbine activity. sponsored by the Department of Energy.

The vehicle has supported numerous DOE-sponsored shows to date, both here in the States and in England. The vehicle has been shipped an estimated 24,300 miles and driven less than 400 miles. The vehicle structure and support systems have had to be continually repaired due to improper shipping and tie-down techniques. The engine, which is the original A926-0 release configuration, has not been removed nor received major service work since installation in September, 1977. A combustor cap was replaced when the linerless insulation was found to be loose. The engine to date has accumulated 80.4 hours of running time and 1384 starts on an original release air bearing.

U-4, 1980 Dodge Mirada

Vehicle U-1, a four-door 1976 Dodge Aspen, was deactivated and its powerplant, Engine 2 (retrofit 4), PP 4-15, was rebuilt for installation in U-4, a 1980 Dodge Mirada. This rebuild includes the first vehicle use of the 18 full and 18 splitter blade impeller with steel inducer. Details of this engine rebuild are discussed in Section 3.2.

After dynamometer qualification, the engine was installed in the Dodge Mirada (Vehicle U-4) which shares the same basic platform and running gear with the Aspen. Vehicle modifications included floor pan rework for increased exhaust system size, engine compartment rework for engine/vehicle system packaging, new pressure-operated heater and A/C system components, A/C compressor and lines, and engine compartment wiring. The distinctively-styled Mirada soft-facia front end provided sufficient room to locate the oil cooler upstream of the A/C condenser for improved cooling performance. Other components were transferred from Vehicle U-1, including intake and exhaust systems, ECU, hot water heat exchanger, A/C condenser, hydraulic brake booster, steering gear, and lightweight front crossmember.

Vehicle U-4 and the engine installation are shown in Figures 18a and 18b.

5.0 CONTROL SYSTEMS

5.1 Familiarization Session at NASA LeRC

Chrysler personnel participated in a control system familiarization session at Lewis Research Center in January, 1980. The class and laboratory sessions included:

- Engine control system overview
- Detailed description of the ECU
- Programming the control system
- Use of the keyboard programmer, diagnostics, and Pro-Log programmer.

Figures 19a and 19b show the session syllabus. An instruction manual was prepared and copies distributed.

A separate NASA contract established with Ultra Electronics provided additional instruction in, and repair service for, their equipment in use at Lewis Research Center.

5.2 Electronic Control Unit Modifications

Gas generator speed signal conditioning for both 18 blade steel inducer installations (engines 2 and 3; PP4-15 and PP2-16) required a circuit change. The rationale for the change is described in Appendix C (Failure Report 82), letter H. P. LeFevre to J. Gross dated March 21, 1980. Other ECU-related deficiencies were noted for future investigation or repair.

5.3 Power Turbine Nozzle Vane Control

Rub blocks were added to Engine 2, PP 4-15, to prevent the power turbine ring gear mesh from jamming (Figure 20). Power turbine nozzle response is being monitored on this installation (Vehicle U-4).

The power turbine nozzle actuator on Engine 7 (PP9-11), NASA LeRC CE-28, was replaced in October due to binding of the output shaft in the engine housing adaptor; see Appendix C (Failure Report 90). The damaged

actuator was later reconditioned and shipped to LeRC as a spare. A service call was required to familiarize LeRC personnel with installation and programming procedures for the nozzle actuator, including

- initial setting of the null valve (FEMA),
- adjustment of the feedback potentiometer for closed loop operation on $T_8/\sqrt{\theta}$, and
- programming and check out.

6.0 DEVELOPMENT TESTING

6.1 Variable Speed Rubber Belt Evaluation

In an effort to characterize the effects of axial pulley forces on variable speed V-belt transmission performance, tests were performed with an existing test rig; see Figure 21.

Test constraints included rig slip and kinematic limits, belt stress level, belt centerline force load cell capacity, and moderate engine torques. Test points, which were each repeated once, are defined in Figure 22. In addition, twenty no-load points were checked to establish minimum drive torque losses.

Some general trends in power, speed, and speed ratio can be seen in Figures 23a thru 23g. Here the efficiency of the drive is plotted against the traction coefficient. The traction coefficient is a measure of the belt lateral loads (pulley axial forces). It is defined as $(T_1 - T_2)/(T_1 + T_2)$, where T_1 and T_2 are the belt tight and slack side tensions, which are functions of torques, belt centerline force, and belt geometry. Some conclusions drawn from this study:

- Reasonably high efficiencies were obtained at moderate loads even with $\pm 4\%$ allowance for measurement error.
- Drive losses were relatively insensitive to changes in traction coefficient.

These data have been analyzed for axial force relationships and controls characterization by NASA; ref. NASA TM-81652 and SAE 810103.

6.2 Regenerator Core/Ring Gear Elastomer

During the period of December, 1979 through March, 1980, three regenerator drive elastomer failures were reported by NASA. All three failures occurred while running at high gas generator speed conditions in Power Plant 9-11, Cell CE-28. These failures are documented in Appendix C (Failure Reports 78, 81, and 83), and detailed discussion will not be repeated here.

However, they can be summarized by stating that, in each case, there was evidence of a possible cause or causes of the failure, but, at the time, none of these could be singled out as the probable cause. It now

appears that the probable cause was, in fact, excessive torque load caused by loss of regenerator running clearance, resulting from distortion of the bulkhead and crossarm sections of the engine housing. This phenomenon can result from prolonged operation at high speeds and cycle temperatures, as discussed on page 2 of Failure Report 83. At that time Chrysler recommended that NASA increase the regenerator running clearance from a nominal 0.040 inch to a minimum of 0.050 inch. This recommendation was followed by NASA personnel, who also removed the baffles restricting bulkhead cooling. Subsequently, no additional elastomer failures have been reported.

During the course of the investigation, as noted above, several other potential sources of the failures were examined, and these activities are summarized below. Many of these are directly related to the ongoing AGT program, and work in these areas is continuing on the Mod 015 contract effort.

Elastomer Strength vs. Temperature.

To aid in checking properties of new shipments of elastomer, and to investigate the elastomer's strength at projected operating temperatures, a shear test fixture was designed and fabricated. Figures 24a and 24b show this fixture as installed in the Instron test machine. Also shown is a typical shear specimen before and after test (see Figure 25). The specimens are prepared under conditions identical to those used for installing ring gears, with the same elastomer thickness (nominally 7 mm.), and with a minimum cross-sectional area of one square inch. In an effort to force the samples to fail in shear (as found at NASA), they were prepared with generous fillet radii on all edges. However, all the room temperature samples failed by peeling rather than in shear, with an average shear load at failure of 330 psi. This compares to the A926 elastomer design shear load of 3.5 psi, implying a room temperature safety factor of about 95 - clearly not a marginal design.

The fixture was then modified to allow shear testing at elevated temperatures, as shown in Figure 26. Preliminary test results, shown on Figure 27, indicate a substantial drop in material properties in the 300-500°F range, but the design safety factor is still 14 at 500°F. It was noted that specimens tested at 500°F and above failed in the shear mode (as compared to the peel mode for the room temperature samples), which matches the failure mode observed at NASA. Samples between 300 and 500°F showed evidence of both failure modes. Testing of Sylgard 186 and candidate replacement materials is continuing with emphasis on the critical 400-600°F range.

Elastomer Strength vs. Gasoline Exposure.

An area of concern is the predicted loss of elastomer properties when exposed to gasoline droplets or vapor. This condition can occur during burner development work or at other times when frequent false starts are experienced. A preliminary evaluation of this effect was made by exposing an earlier-design shear specimen to concentrated gasoline vapors for twenty hours prior to room temperature test. The elastomer showed marked swelling, with resulting lower durometer and higher elongation, but still sustained a load of 70 psi before failing in the peel

appears that the probable cause was, in fact, excessive torque load caused by loss of regenerator running clearance, resulting from distortion of the bulkhead and crossarm sections of the engine housing. This phenomenon can result from prolonged operation at high speeds and cycle temperatures, as discussed on page 2 of Failure Report 83. At that time Chrysler recommended that NASA increase the regenerator running clearance from a nominal 0.040 inch to a minimum of 0.050 inch. This recommendation was followed by NASA personnel, who also removed the baffles restricting bulkhead cooling. Subsequently, no additional elastomer failures have been reported.

During the course of the investigation, as noted above, several other potential sources of the failures were examined, and these activities are summarized below. Many of these are directly related to the ongoing AGT program, and work in these areas is continuing on the Mod 015 contract effort.

Elastomer Strength vs. Temperature.

To aid in checking properties of new shipments of elastomer, and to investigate the elastomer's strength at projected operating temperatures, a shear test fixture was designed and fabricated. Figures 24a and 24b show this fixture as installed in the Instron test machine. Also shown is a typical shear specimen before and after test (see Figure 25). The specimens are prepared under conditions identical to those used for installing ring gears, with the same elastomer thickness (nominally 7 mm.), and with a minimum cross-sectional area of one square inch. In an effort to force the samples to fail in shear (as found at NASA), they were prepared with generous fillet radii on all edges. However, all the room temperature samples failed by peeling rather than in shear, with an average shear load at failure of 330 psi. This compares to the A926 elastomer design shear load of 3.5 psi, implying a room temperature safety factor of about 95 - clearly not a marginal design.

The fixture was then modified to allow shear testing at elevated temperatures, as shown in Figure 26. Preliminary test results, shown on Figure 27, indicate a substantial drop in material properties in the 300-500°F range, but the design safety factor is still 14 at 500°F. It was noted that specimens tested at 500°F and above failed in the shear mode (as compared to the peel mode for the room temperature samples), which matches the failure mode observed at NASA. Samples between 300 and 500°F showed evidence of both failure modes. Testing of Sylgard 186 and candidate replacement materials is continuing with emphasis on the critical 400-600°F range.

Elastomer Strength vs. Gasoline Exposure.

An area of concern is the predicted loss of elastomer properties when exposed to gasoline droplets or vapor. This condition can occur during burner development work or at other times when frequent false starts are experienced. A preliminary evaluation of this effect was made by exposing an earlier-design shear specimen to concentrated gasoline vapors for twenty hours prior to room temperature test. The elastomer showed marked swelling, with resulting lower durometer and higher elongation, but still sustained a load of 70 psi before failing in the peel

mode. In future tests, the effect of gasoline vapor on hot strength will also be documented. It should be noted that fluorosilicone coatings are available for use in protecting the silicone elastomer from attack by hydrocarbons if needed.

Increased Elastomer Area Design.

Should it be determined that reduced shear load on the A926 regenerator drive elastomer is needed, a design with increased elastomer shear area has been proposed. This design, shown schematically in Figure 28, is an adaptation of the AGT configuration. It permits an increase in elastomer shear area by at least 75%, reducing maximum shear load to approximately 2 psi. Other advantages include:

- An increase in the relative elastomer surface area exposed to cooling air flow.
- A shorter heat flow path length between source (matrix) and sink (ring gear).
- An increase in the number of individual elastomer segments - from 9 to 36 - to improve load-sharing capacity of the remaining pads should a single pad failure occur.

Detailing of this design will not be initiated unless needed.

Graphite Seal Friction vs. Moisture Content.

As discussed on page 3 of Failure Report 81 in Appendix C, graphite seals are subject to contamination with atmospheric moisture, resulting in momentarily higher friction loads until the heat of friction and/or combustion can evaporate it. Preliminary tests, using small samples of graphite statically loaded on a representative matrix surface, showed that breakaway torque can double in the presence of moisture (see Figure 29). However, for this condition to seriously affect elastomer life, a condition of maximum load and zero regenerator speed would have to be achieved (equivalent to 100% gas generator speed and a stalled power turbine) - an impossible situation. No additional investigation in this area is planned, although the seal friction and wear test machines now in operation could be used for further evaluation of graphite seal dynamic friction vs. moisture content should the need arise.

Excessive Core Speed Rate of Change.

During this investigation, the question was raised as to the possibility that rapid changes in engine output shaft speed, imposed by cell CE-28's programmable dynamometer, could cause excessive elastomer loads. A subsequent review of the cell's dynamometer speed vs. time traces, supplied by NASA, showed that there was no cause for concern; maximum rate of dynamometer speed change indicated was 700 RPM per second.

7.0 MISCELLANEOUS

7.1 Delivery of Parts

Twenty-seven individual requests for engine parts and/or information

were made by NASA personnel from October, 1979 to February, 1981. An itemized list of all parts shipped, arranged in reverse chronological order, is shown on Figure 30. Air freight services were utilized to expedite deliveries.

7.2 Inventory, DOE Government-Owned Capital Property

In accordance with a letter dated April 10, 1980 from R. H. Bauer, Manager/Regional Representative, U.S. Dept. of Energy, Chicago Operations and Regional Office, Financial Management Division, 9800 South Cass Ave., Argonne, Ill. 60439, Chrysler Corporation prepared the first semi-annual capital inventory of DOE Government-owned property.

This property is part of the NASA-managed automotive gas turbine development program and is presently at two locations:

1. Chrysler Corporation
12800 Lynn Townsend Drive
Highland Park, Michigan 48231
2. NASA Lewis Research Center
21000 Brook Park Road
Cleveland, Ohio 44135

This inventory, not included in this report, is available upon request.

Additionally, a summary of spare parts procured during this contract period is appended as Figures 31a and 31b.

7.3 Parts Failure Reporting

Part failures and deficiencies were routinely reported as an ongoing activity of the service contract. Twenty Failure Reports were written and are attached as Appendix C. Air bearing failures were the most significant Upgraded engine deficiency that impacted on the development programs at NASA. Regenerator ring gear/core elastomer failures contributed next to test cell down time.

The vehicles were plagued with frame and structural damage induced by improper chassis tie-down techniques employed by commercial carriers responsible for transporting the vehicles. Chassis tie-downs and adjacent structures were reinforced on all vehicles. Coordination of activity between the carriers and knowledgeable corporate personnel did reduce the damage problem.

8.0 CONCLUSIONS

1. All requests for vehicle exhibits, displays and demonstrations were met.
2. Transportation of vehicles via commercial carrier resulted in an inordinate amount of chassis damage attributed to tie-down procedures. Reinforcement of the chassis structure and correct tie-down procedure minimized this problem.
3. Ongoing maintenance of test engines at NASA LeRC, Cleveland, Ohio, and Chrysler Corporation, Detroit, Mich., was accomplished.

4. The CTW air bearing demonstrated unacceptable reliability in test cell engines. No air bearing failures were experienced during limited vehicle testing.
5. Several total and partial failures of the regenerator-to-ring-gear elastomer were experienced in NASA test engines at LeRC. These were attributed to high engine speeds and cycle temperatures experienced at LeRC. The problem was alleviated by removal of engine housing temperature control baffles and increased regenerator seal clearance (.040 in. to .050 in.).
6. The Upgraded engine parts lists and prints were updated. Microfilms were delivered to NASA.
7. One vehicle was updated: U-1, Dodge Aspen (1976 model) to U-4, Dodge Mirada (1980 model).
8. Gas generator compressor sections of engines tested at LeRC exhibited significantly more impeller/diffuser dirt deposits than engines tested at Chrysler, in both cells and vehicles. This problem was attributed to the air handling systems at LeRC.
9. An inventory of parts/equipment was completed and the results were reported to NASA.
10. A marginal supply of spare parts for the Upgraded engines and vehicles resulted in some difficulty in effectively sustaining the program. Some aerodynamic components, e.g., power turbine and compressor turbine wheels, were classified as limited service.
11. The level of technical support to NASA diminished significantly as LeRC personnel gained experience and familiarity with automotive procedures and rationale. Transmittal of the documentation of engine builds, test hours, and test procedures to Chrysler could be improved.

9.0 RECOMMENDATIONS

1. The air bearing design should be modified for foil attachment by means other than spot welding, to achieve satisfactory service life.
2. Emphasis should be directed increasingly to vehicle systems operating in real-world situations.
 - A. Electronic control system inconsistencies and lack of reliability should be resolved.
 - B. Maximum use of vehicles for routine commuting and intercity travel should be encouraged to promote identification and resolution of real problems as opposed to dynamometer-duty problems. Actual fuel economy should be documented for comparison with EPA cycle values.
 - C. Vehicles should be made easily identifiable as gas-turbine-powered to better assess public acceptance and support for the program.

3. Polyimide outer regenerator seals should replace the original, costly and fragile graphite parts whenever convenient.
4. Compressor diffusers should be replaced by new parts which are "closed" 1.5° (design available) to achieve improved compressor surge margin at maximum power conditions, so that full engine and vehicle performance potential can be achieved.
5. An adequate supply of spare parts should be established, especially long-lead items such as turbine wheels and regenerator assemblies.
6. Analysis of the rotor shaft dynamics (tests of Engine 1, PP3-13) should be completed by a consortium of Chrysler, NASA, and MTI personnel. Additional testing of rotor imbalance modes is also encouraged.
7. Further demonstration of the LPP combustor concept is recommended in both test cell and vehicle. Use of a ceramic reactor tube section would avoid the durability problem of the metal tube and promote ceramic technology.
8. Vehicle sound levels should be documented, including the SAE J986b drive-by procedure, idle, and road load conditions.
9. An investigation should be conducted on the factors that influence reduction gearing noise. These factors would include pinion gear to rotor shaft attachment, rotor bearing spring and damping rates, tooth finish and contour, and lubrication variables.
10. An effort should be made to improve engine/vehicle response from idle. Redesign of the turbomachinery for reduced inertia and/or improved idle load control (to permit an efficient, higher idle speed) would be directly effective.
11. Improved, simplified, and better co-ordinated record keeping would help keep Chrysler and NASA Lewis personnel aware of current status of problems, parts, priorities, and achievements.

ENGINE STATUS

JAN. 1981

ENGINE No.	RETROFIT	PP No.	STATUS		
			PRESENT	FUTURE	
1	*R1	3-13	CHRYSLER	CHRYSLER	SHAFT DYNAMICS ACT DEVELOPMENT - Regenerator Core Elastomer - Warm up Fuel - Polyimide Outer Regenerator Seal
2	R4	4-15	U4	U4	Dodge Mirada Support to DOE
3	R5	2-16	NASA	NASA	Evaluation of Modified Interstage Combustor Development
4	-	5-4	NASA		Inactive Original 926 Release
5	-	8-10	U3	U3	Chrysler LeBaron Support to DOE Original 926 Release
6	R2	10-14	U2	U2	Dodge Aspen Support to DOE
7	*R3	9-11	NASA	NASA	Transient Test Cell

FIGURE 1

* NOEL PENNY POWER TURBINE STAGE

NOTE: VEHICLE U-1 HAS BEEN DEACTIVATED AND REPLACED BY U-4.

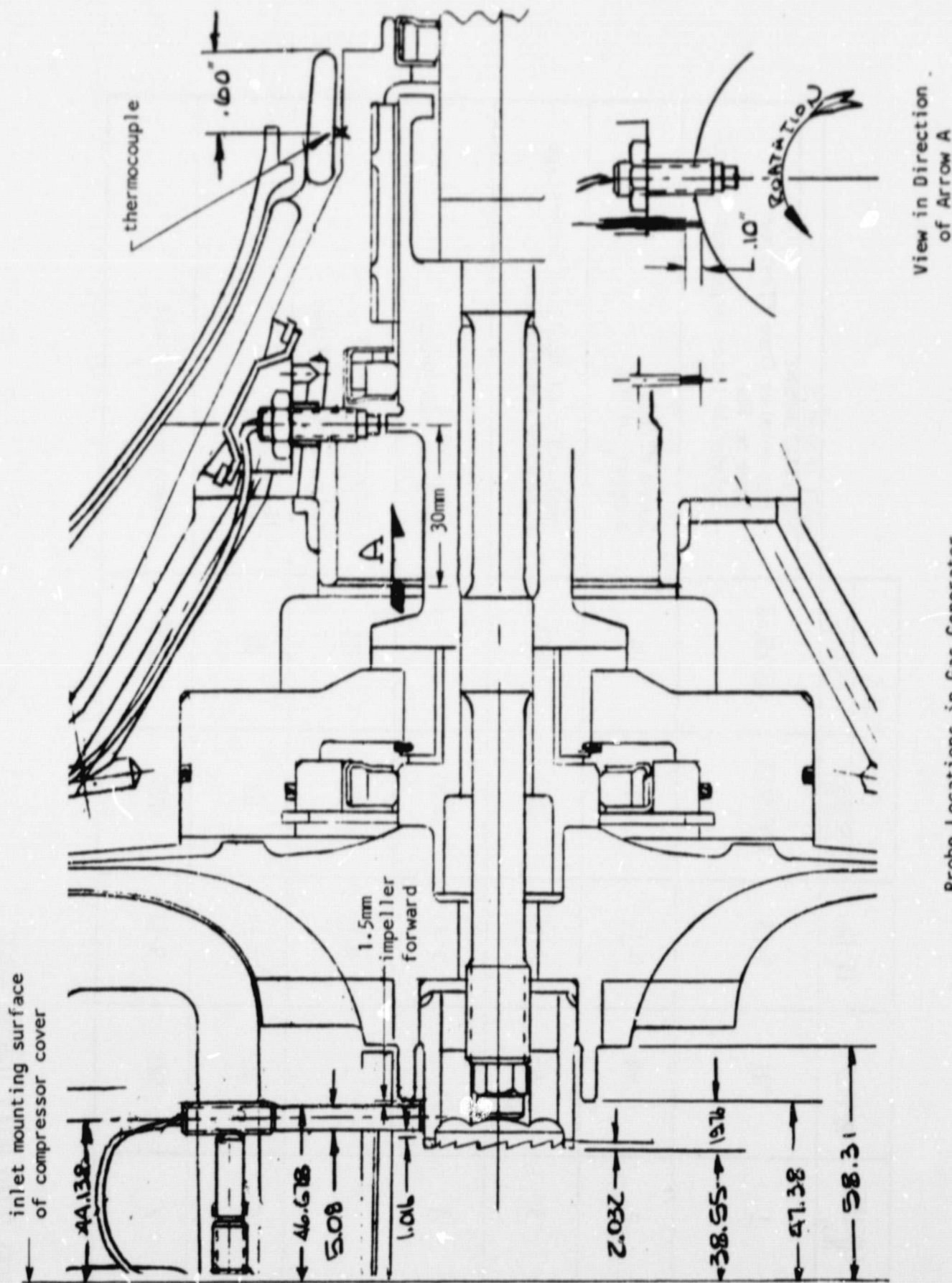


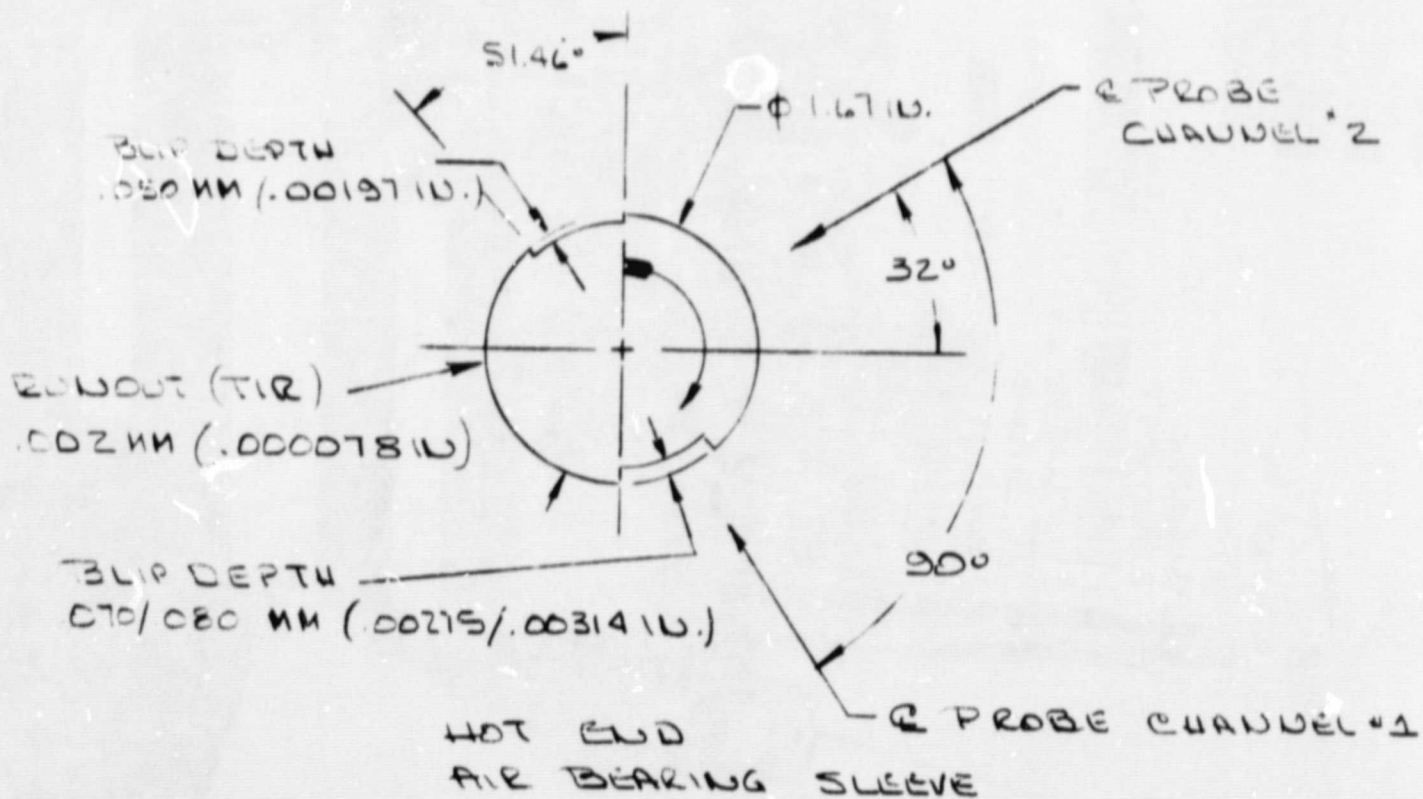
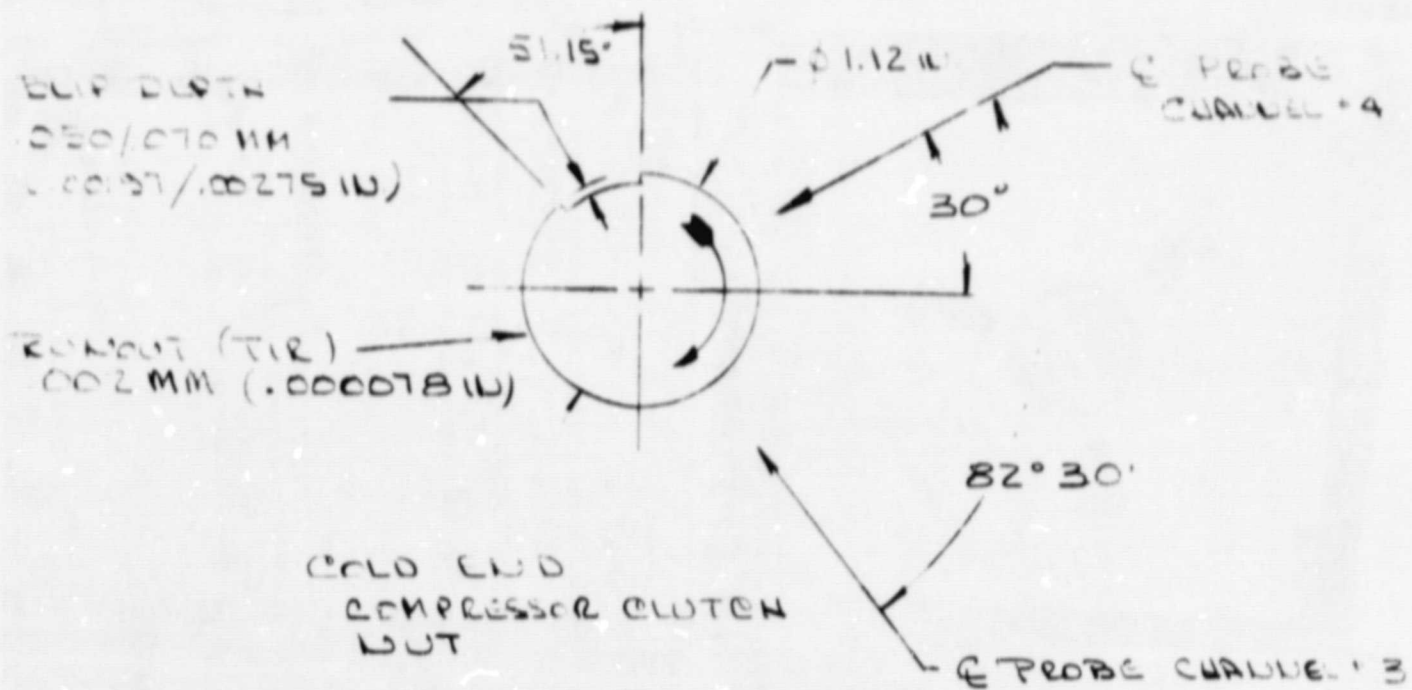
FIGURE 2

ADJUSTED VALUES

3EH - UCS: .0004 LEFT, .00035 RIGHT (02-11)

PP 3-134

648 622 x 18



Probe Orientation -- Shaft Dynamics

FIGURE 3

6-5-80

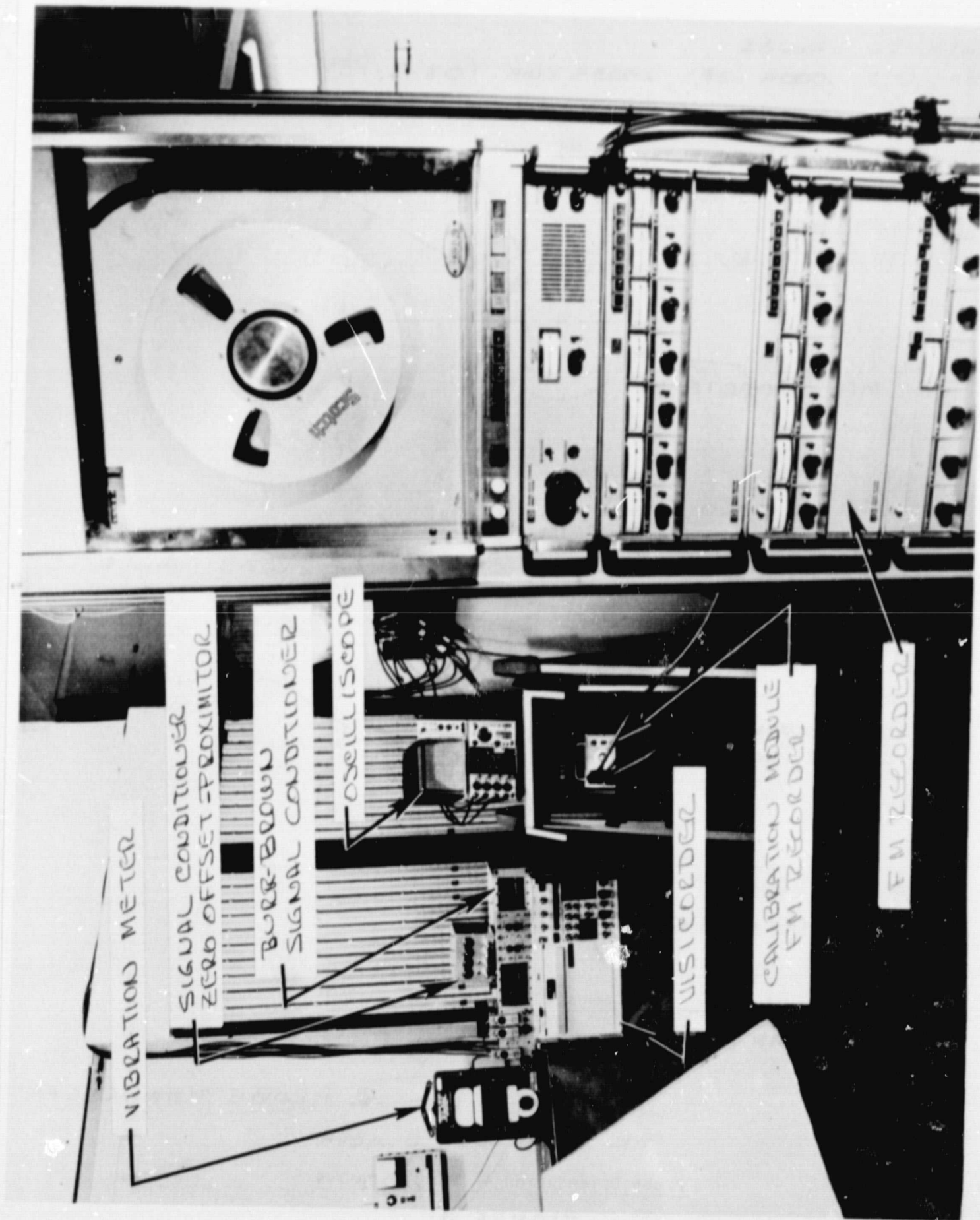
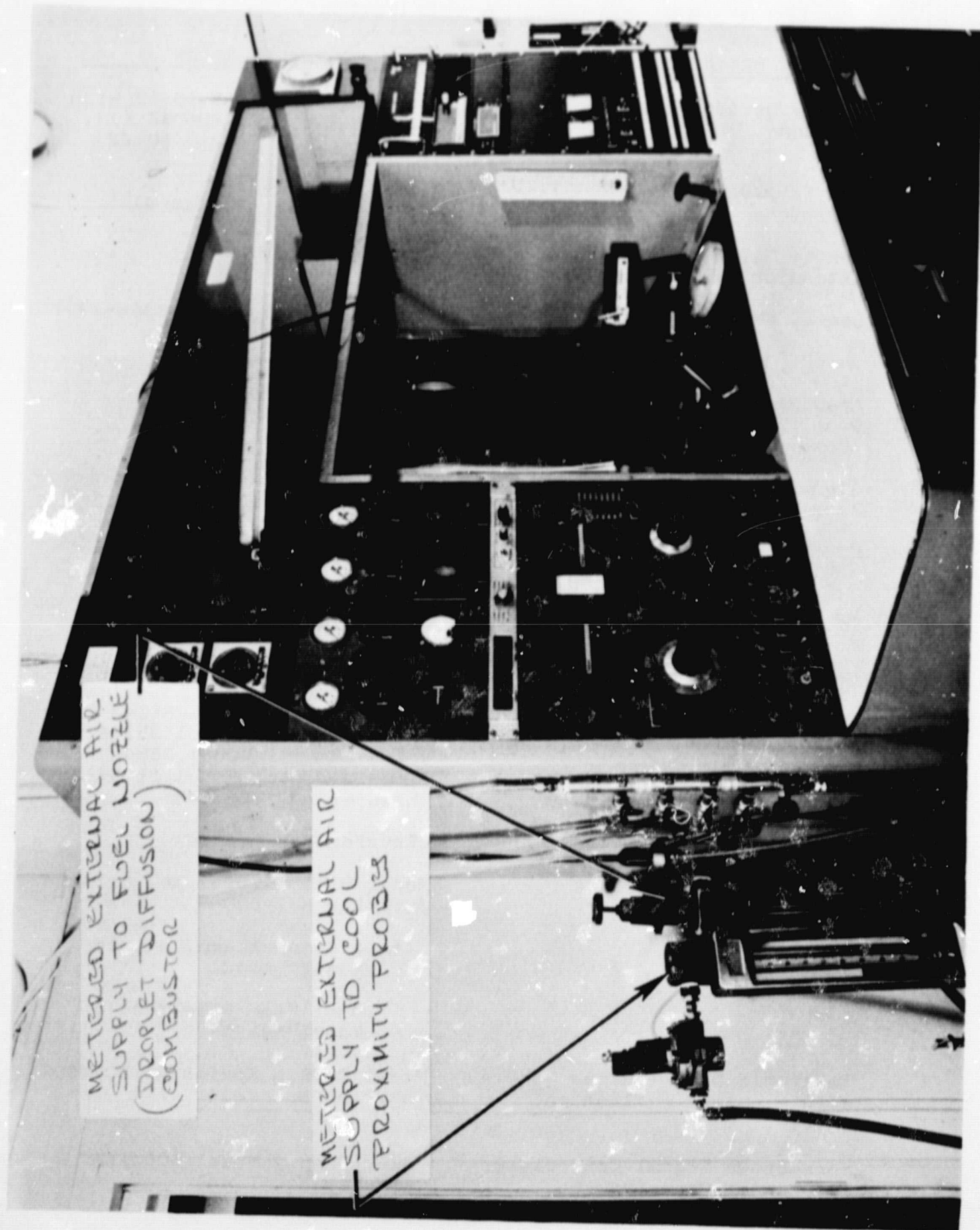


FIGURE 4a



METERED EXTERNAL AIR
SUPPLY TO FUEL NOZZLE
(DROPLET DIFFUSION)
(COMBUSTOR)

METERED EXTERNAL AIR
SUPPLY TO COOL
PROXIMITY PROBES

FIGURE 4b

LIST OF SPECIAL INSTRUMENTATION SHAFT DYNAMICS

<u>QTY.</u>	<u>DESCRIPTION</u>	<u>IDENTIFICATION</u>
2	Bently Nevada Proximity Probes Hot Zone	Type 190-00-00-07-18-02 with Ceramic Tip S/N: 408088 (1), 408090 (2)
2	Bently Nevada Proximity Probe Cold Zone	Type 125-FL-18 S/N 14145(3), 214144(4)
4	Bently Nevada Co-Axial Extension Leads	Type 2789-144
4	Bently Nevada Proximitors	Model 20931-02 (3115-2388-190) S/N 87653(1), 87646(2), 87673(3), 87582(4)
1	Acopian Regulated Power Supply Supply with CORCOM EMI Filter (Power Source for Proximitors)	Model B186750 Type 7444-1K3-1 amp
1	Signal Conditioner Zero Offset- Proximity Probes.	Chrysler fabricated
1	MB Electronics Vibration Meter	Model-M6, Serial No. 764 Chrysler No. 10540
2	MB Vibration Pickups 1 vert axis, 1 horiz. axis	Type 124
1	Honeywell Visicorder	Model 1858 Chrysler No.22195
1	Hewlett Packard FM Tape Recorder - 14 Channel	Repro.Section-Model 3514A Record Section-Model 3513A Voice Channel-Model 3604A Tape Transport-Model 3525A Chrysler No. 169.049
1	Calibration Module-FM Recorder	Chrysler Fabricated
1	Tektronix Oscilloscope	Model 5113 Serial No. B114214 Chrysler No.-2206 with:4 channel amp. module Model 5A14N :Dual Time Base Module Model 5B12N
1	Tektronix Oscilloscope Camera with Electronic Flash and Shutter	Model C-5B Serial No.B024009 Chrysler No.-2294
1	Burr-Brown Signal Conditioner- 12 Channel Capacity	Power Supply Model 506/16A Chrysler No. 15441

FIGURE 5

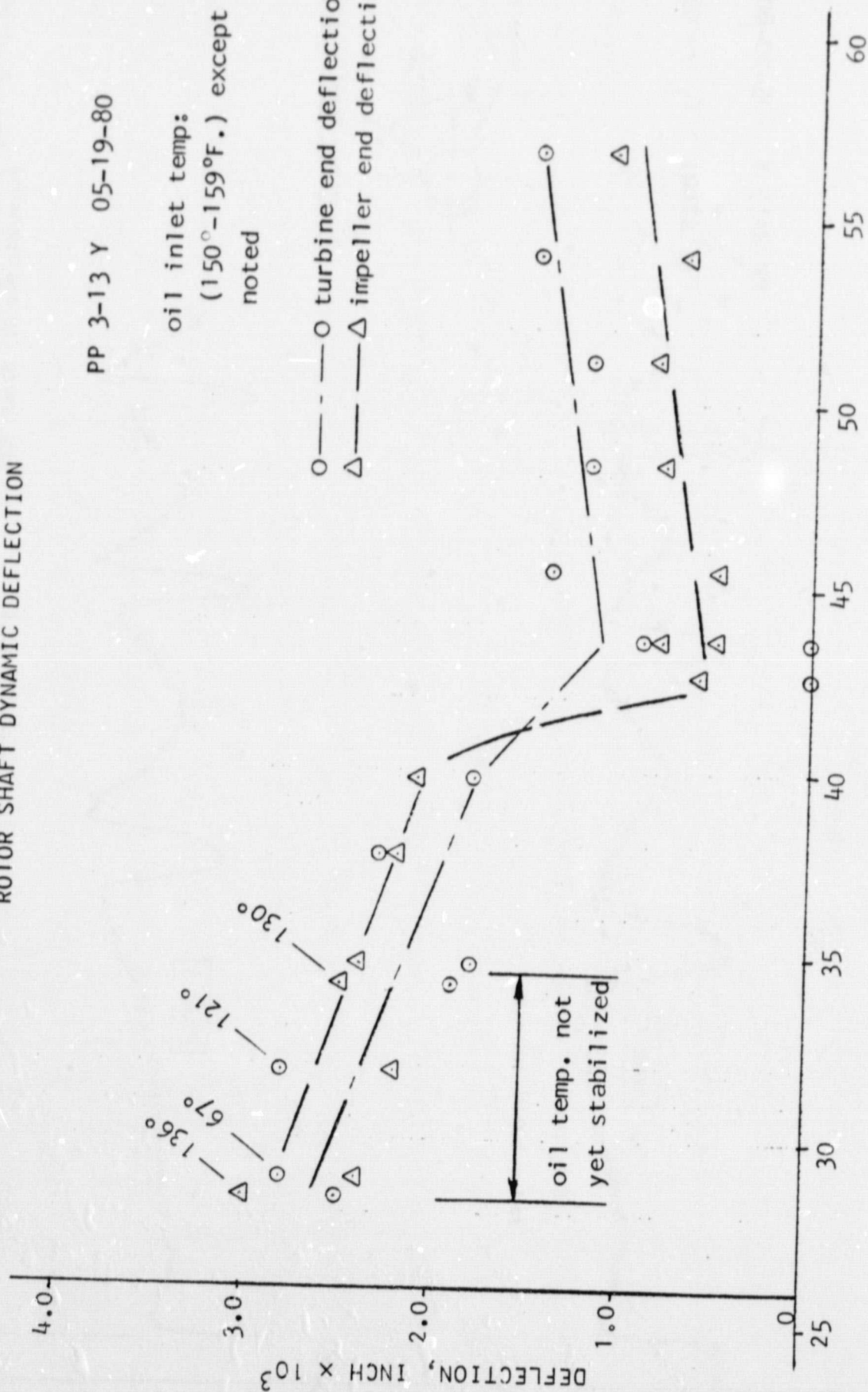
UPGRADED ENGINE

ROTOR SHAFT DYNAMIC DEFLECTION

PP 3-13 Y 05-19-80

oil inlet temp:
(150°-159°F.) except as
noted

○ — — — ○ turbine end deflection
△ — — — △ impeller end deflection

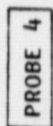


GAS GENERATOR SPEED, RPM x 10⁻³

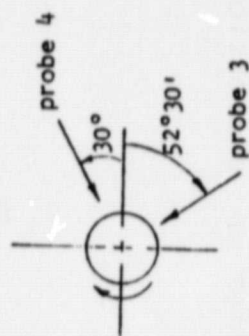
FIGURE 6

Start Cycle at Crank

1st START $T_1 \sim 50^\circ\text{F}$



spike= 0.0024 in. avg.



rear view - impeller end



KEY ON

0.015 SEC.

GAS GEN. SPEED (10,000 rpm/unit)

	1449	66	1460	66	1480	66	1500	66	1520	66	1540	66	1560	66	1580	66	1600	66	1620	66	1640	66	1660	66	1680	66	

FIGURE 7a

ROTOR SHAFT DYNAMICS TESTS
Displacement vs. Time
Start Cycle at Crank

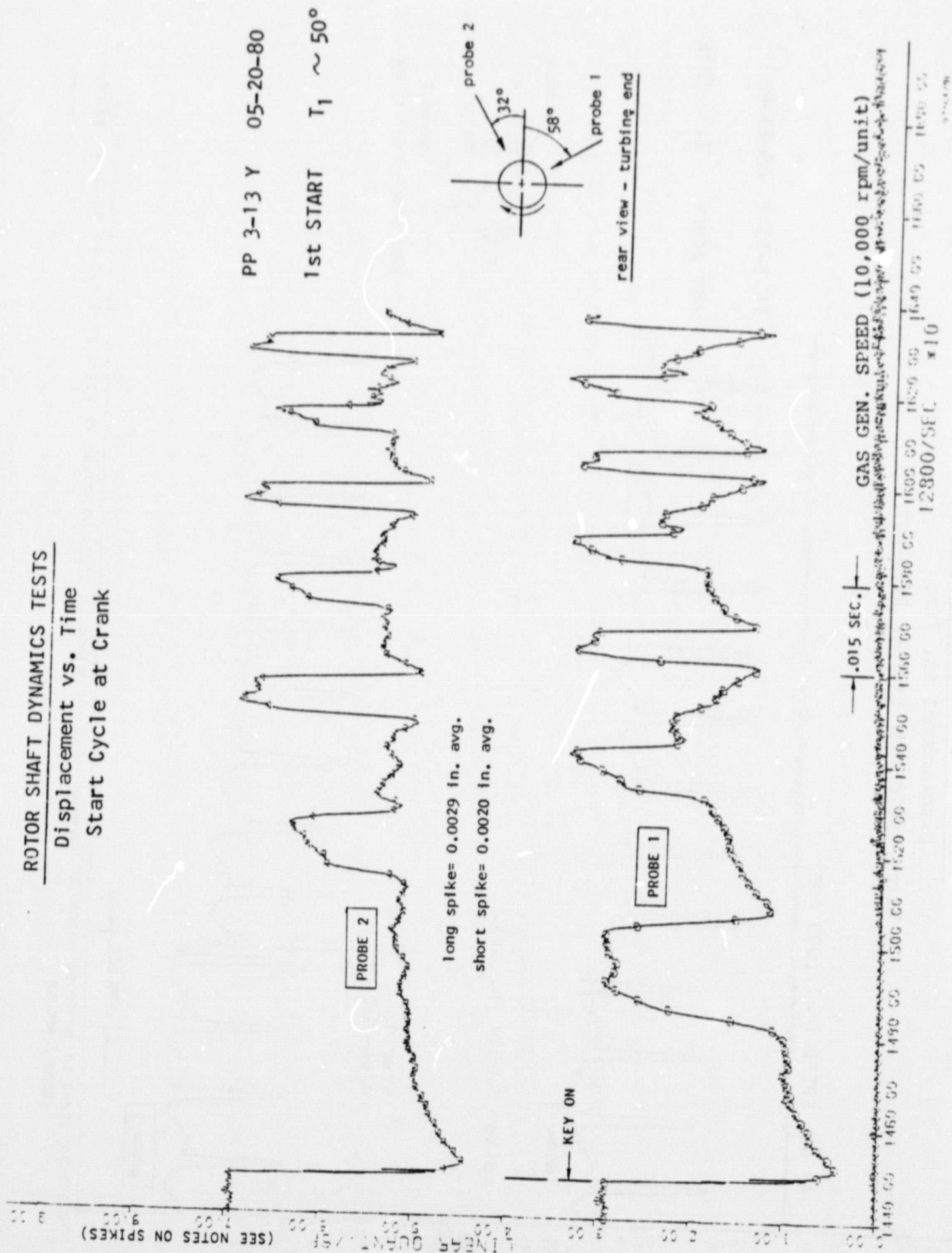


FIGURE 7b

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

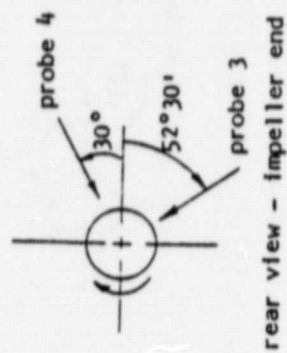
Start Cycle Near Starter Drop-out

GAS GEN SPEED (~17,000 rpm)

Handwritten note: This is the first start cycle after a 10 minute run at 17,000 rpm.

PP 3-13 Y 05-20-80

1st start $T_1 \sim 50^\circ\text{F}$



spike = 0.0024 in. avg.

starter drop-out

.005 SEC.
12800 / SECOND

FIGURE 7c

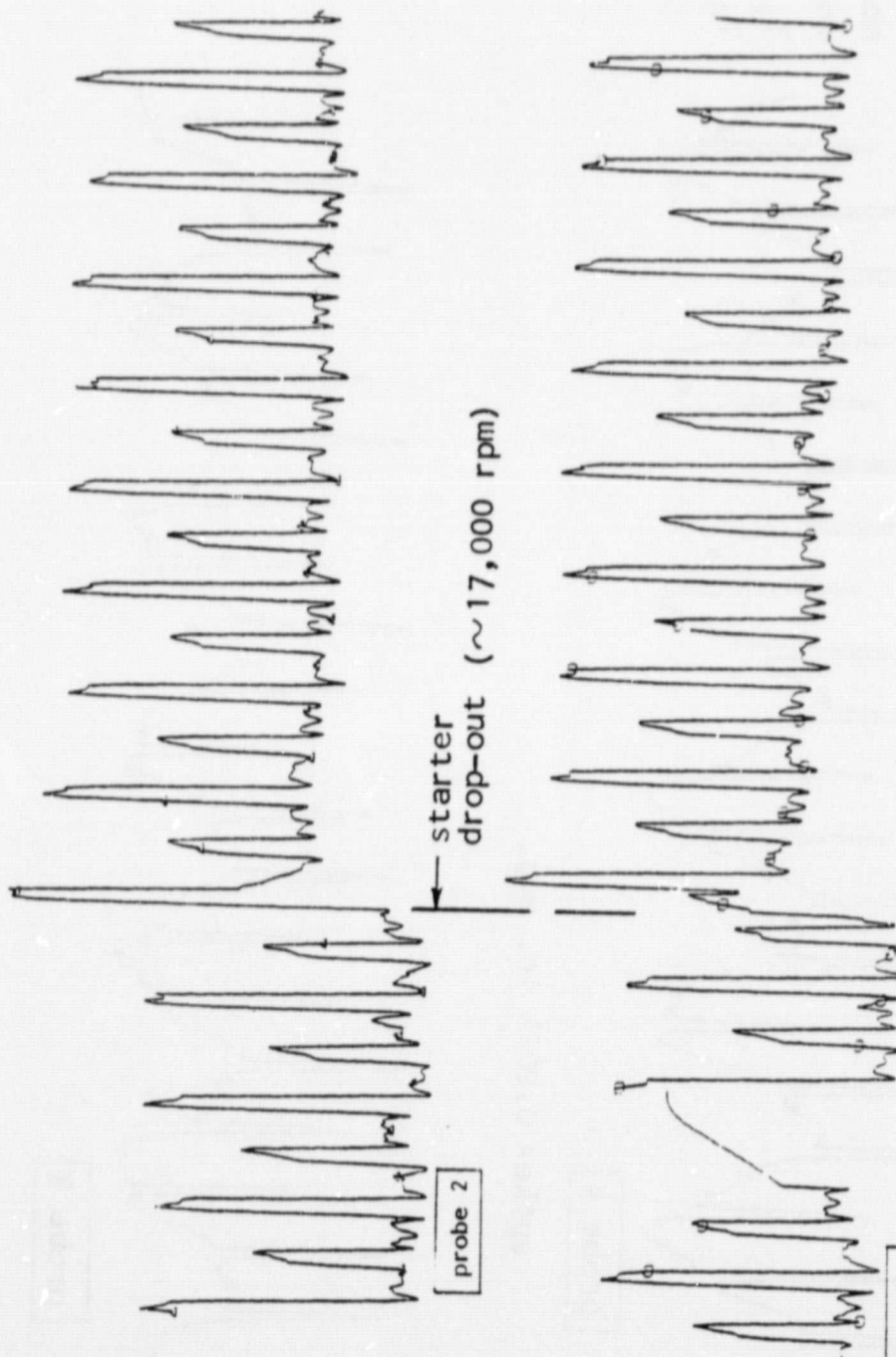
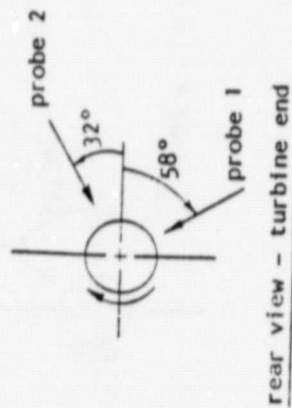
ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Start Cycle Near Starter Drop-out

PP 3-13 Y 05-20-80

1st start $T_1 \sim 50^\circ\text{F}$



long spike = 0.0029 in. avg.

short spike = 0.0020 in. avg.

12800 / SECOND

FIGURE 7d

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Steady State 50% Ngg

PP 3-13 Y 05-20-80
run 366
mech. speed 28,300 rpm
engine oil inlet 166°F
T₁ 50°F
T₅ 1418°F

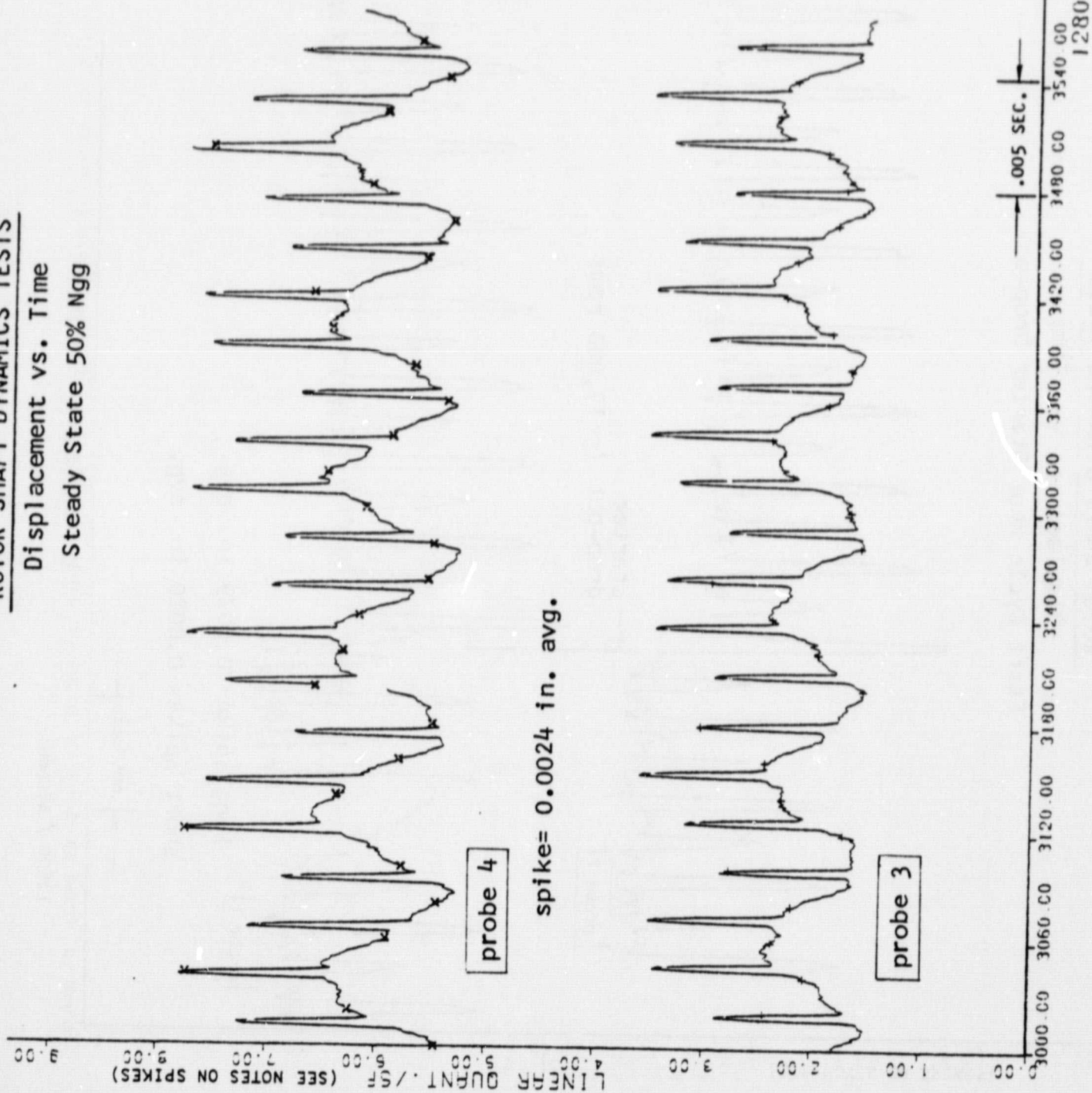
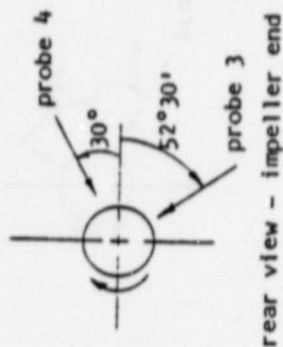
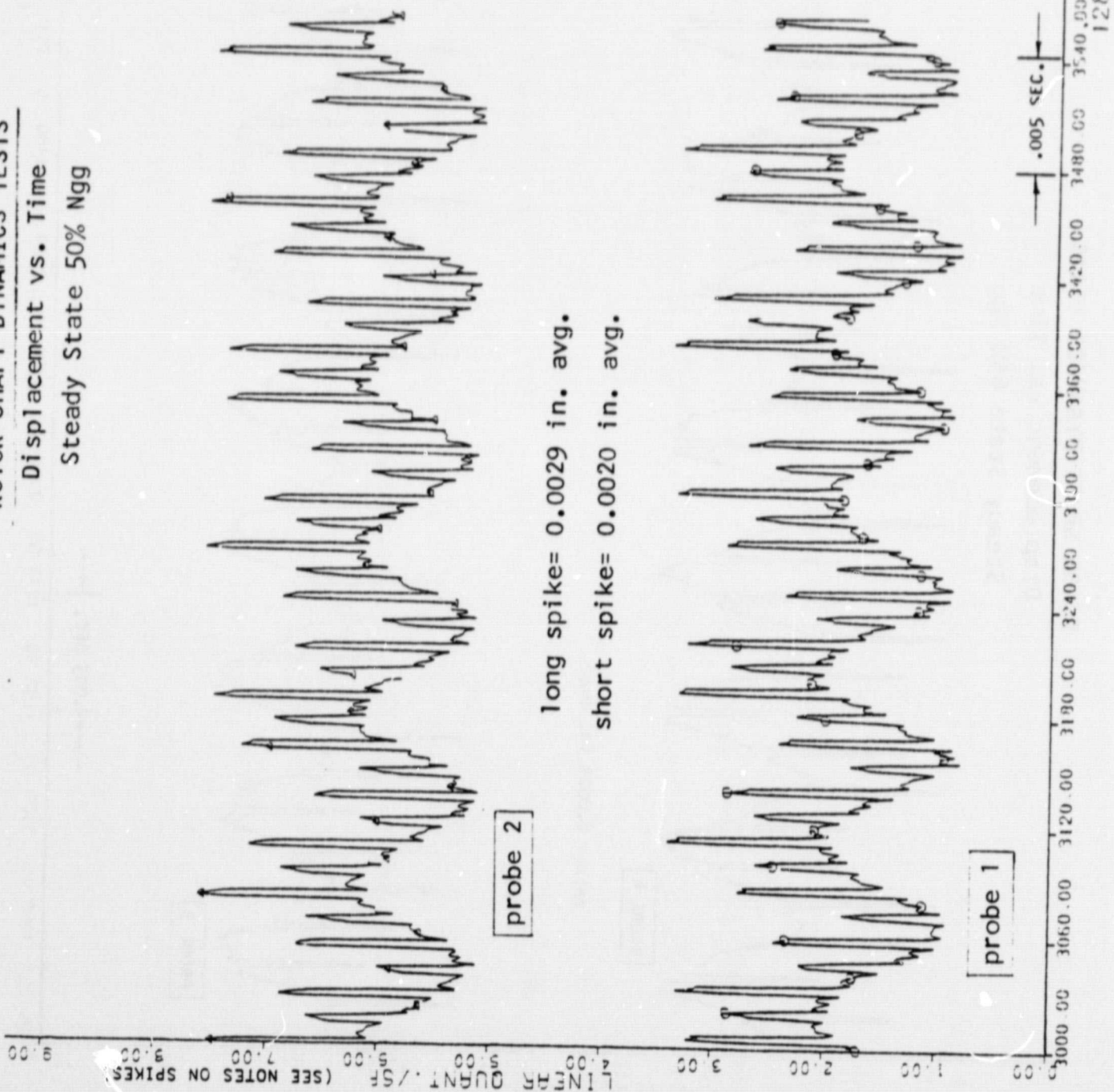


FIGURE 7

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Steady State 50% Ngg



PP 3-13 Y 05-20-80
run 366
mech. speed 28,300 rpm
engine oil inlet 166°F
T₁ 50°F
T₅ 1418°F

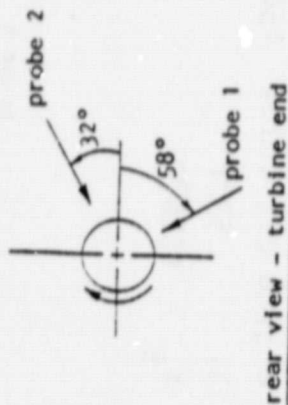
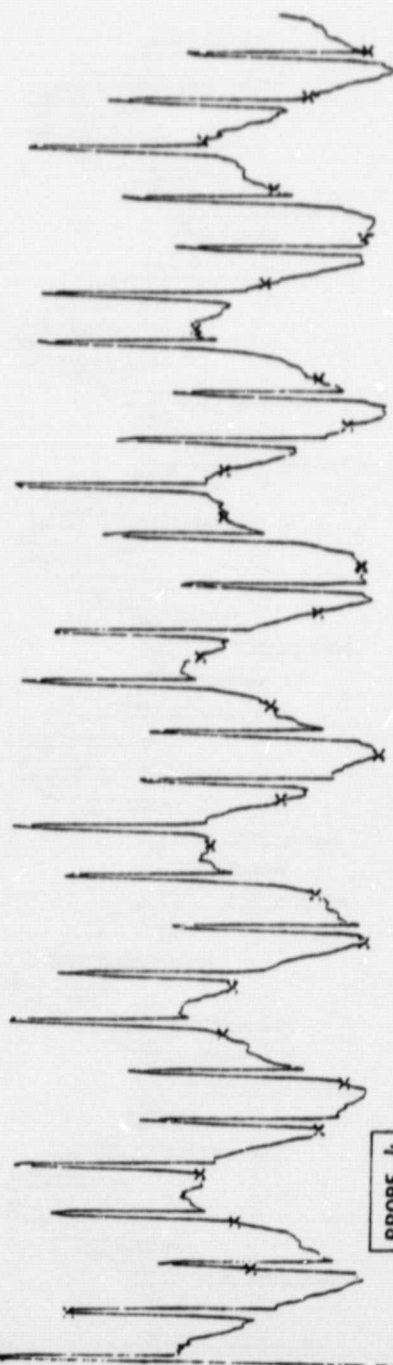


FIGURE 71

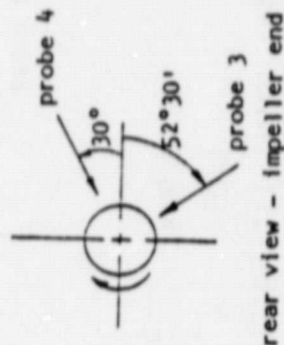
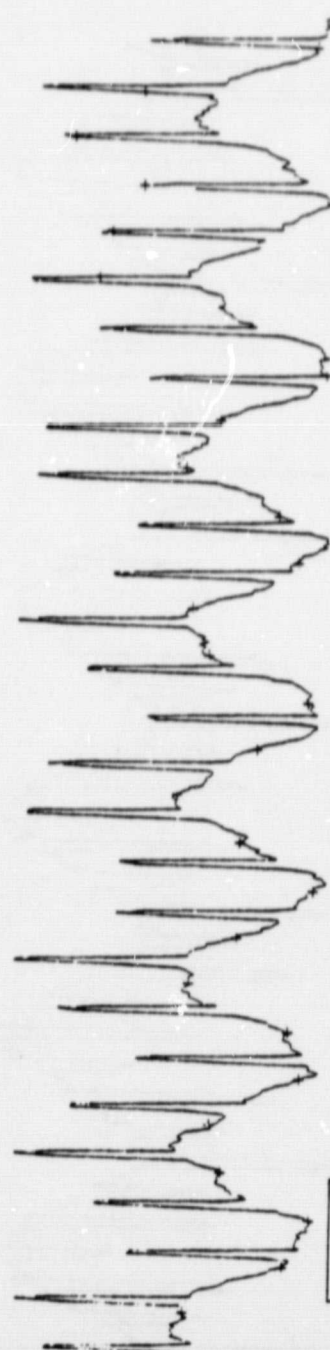
ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Steady State 65% Ngg



spike = 0.0024 in. avg.



PP 3-13 Y 05-20-80
run 369
mech. speed 36,900 rpm
engine oil inlet 156°F
T₁ 53°F
T₅ 1526°F

FIGURE 7g

← .005 SEC. →

3000.00	3060.00	3120.00	3180.00	3240.00	3300.00	3360.00	3420.00	3480.00	3540.00	3600.00	3660.00
1:800/51 C											

ROTOR SHA DYNAMICS TESTS
Displacement vs. Time
 Steady State 65% Ngg

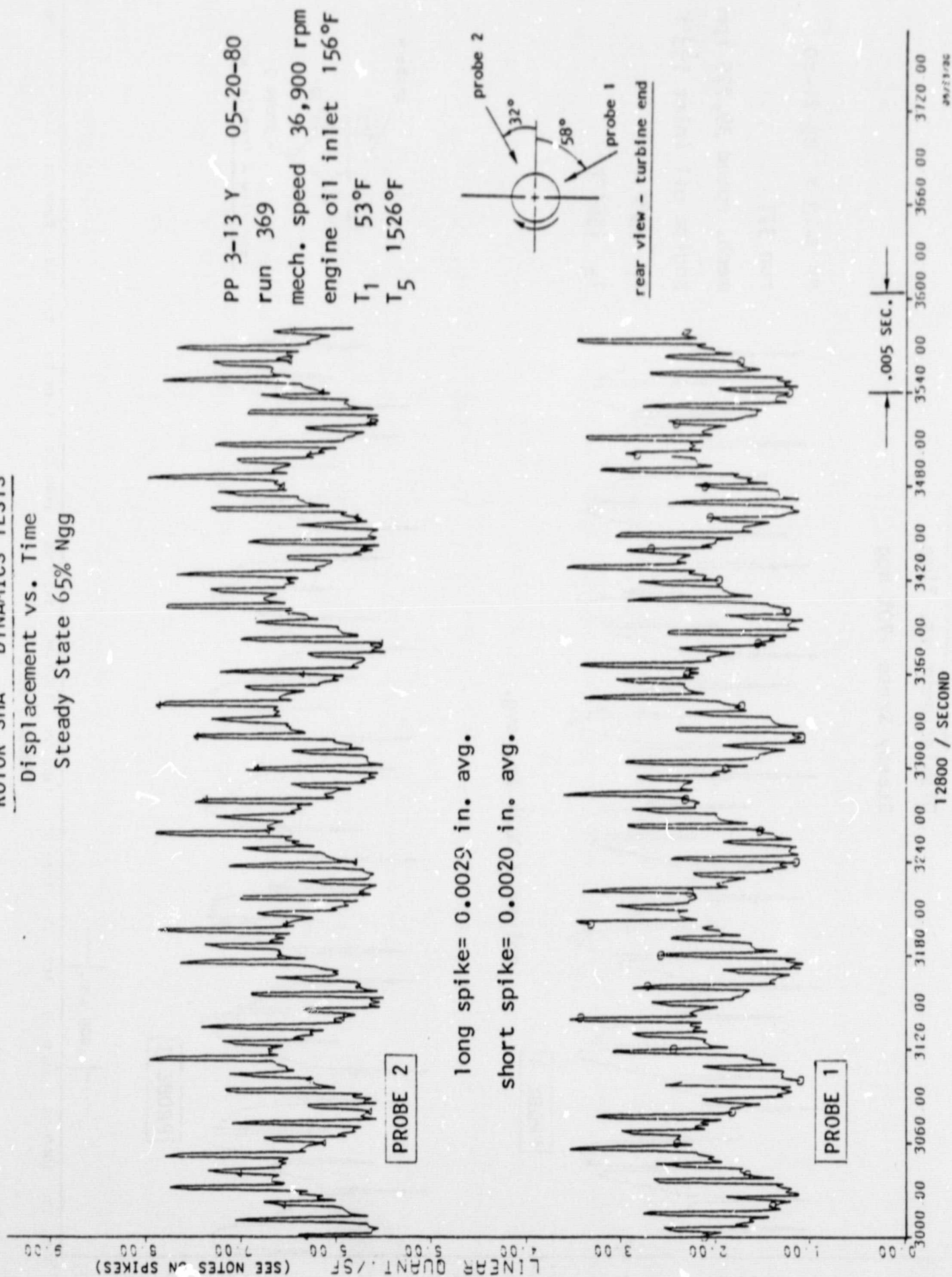


FIGURE 7h

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Steady State 70% Ngg

PP 3-13 Y 05-21-80

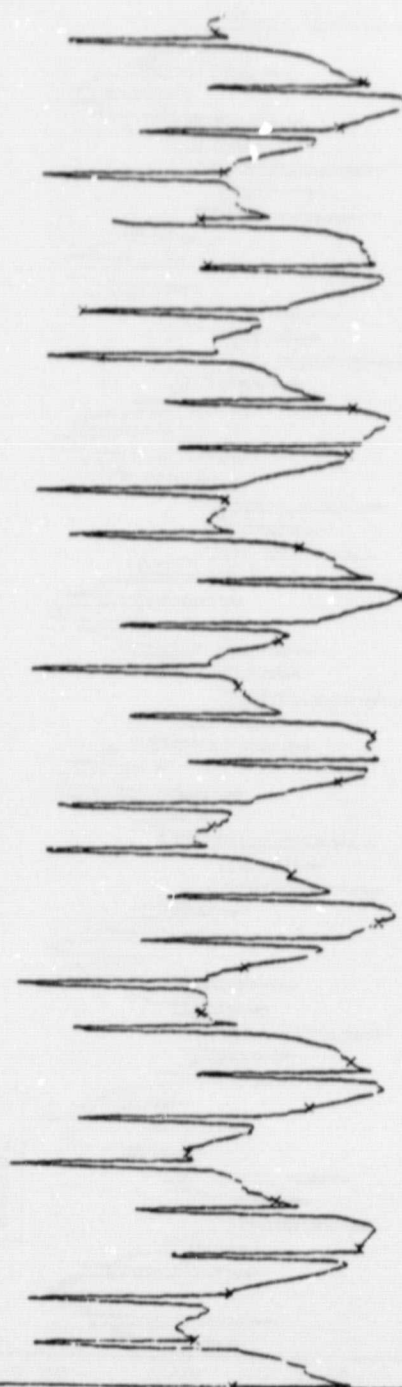
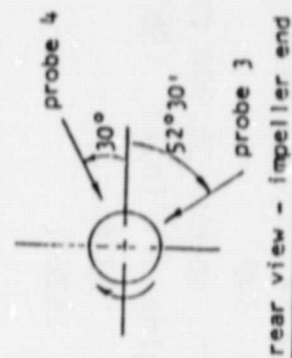
run 371

mech. speed 39,725 rpm

engine oil inlet 153°F

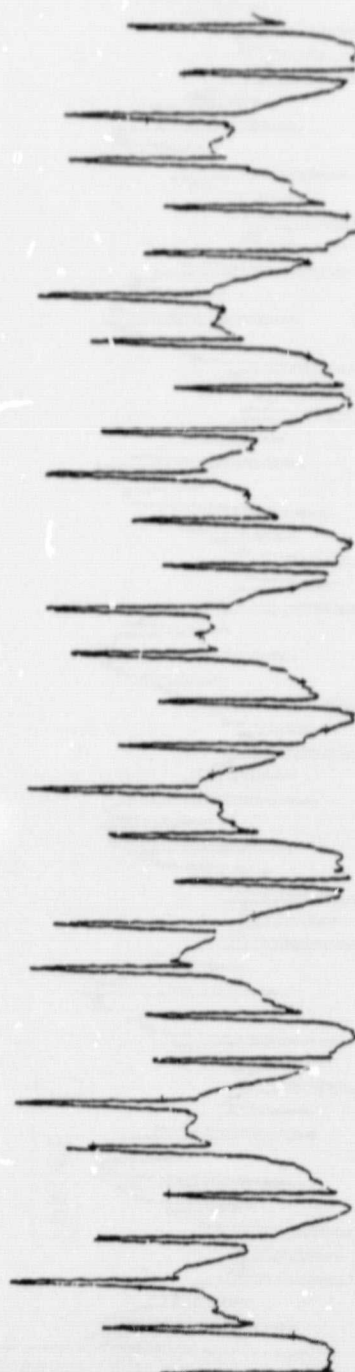
T₁ 53°F

T₅ 1561°F



PROBE 4

spike= 0.0024 in. avg.



PROBE 3

0.005 sec.

12800 / SEC.

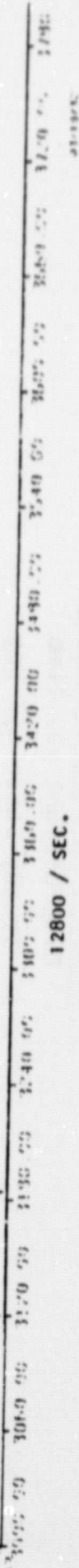


FIGURE 71

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Steady State 70% Ngg

PP 3-13 Y 05-21-80
run 371
mech. speed 39,725 rpm
engine oil inlet 153°F
T₁ 53°F
T₅ 1561°F

PROBE 2

long spike= 0.0029 in. avg.

short spike= 0.0020 in. avg.

PROBE 1

.005 sec.

12800 / SEC.

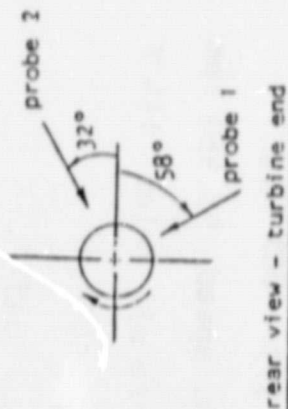
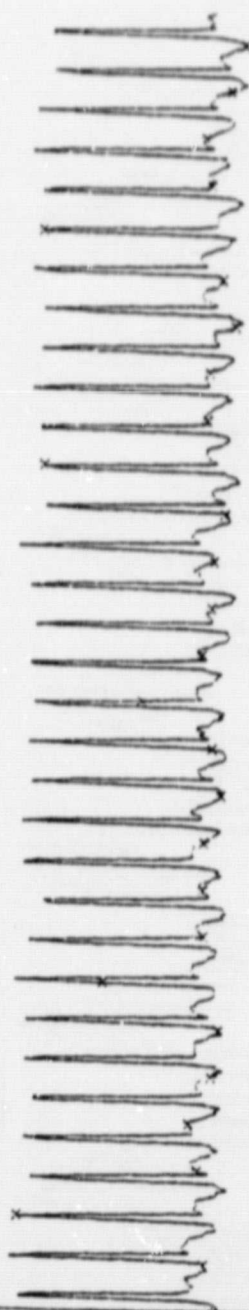


FIGURE 7J

ROTOR SHAFT DYNAMICS TESTS

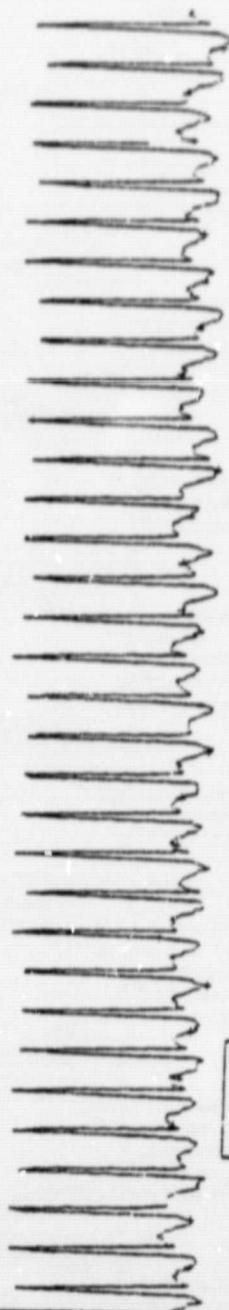
Displacement vs. Time

Steady State 80% Ngg



PROBE 4

spike = 0.0024 in. avg.



PROBE 3

0.005 sec.

12800 / sec.

PP 3-13 Y 05-21-80
run 373 80% Ngg
mech. speed 45,450 rpm
engine oil inlet 154°F

T₁ 54°F.

T₅ 1648°F.

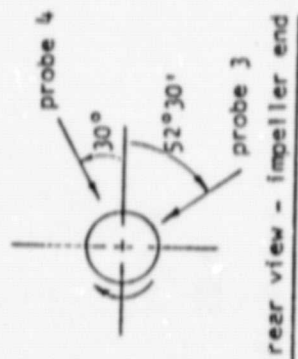


FIGURE 7k

ROTOR SHAFT DYNAMICS TESTS

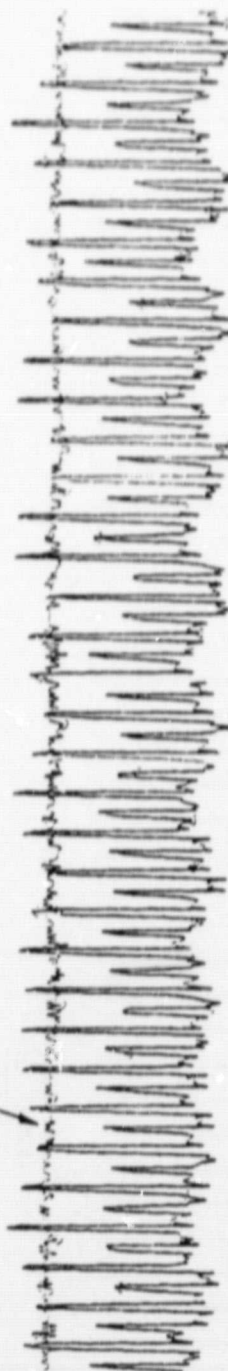
Displacement vs. Time
Steady State 80% Ngg

T5



(SEE NOTE ON SPIKES)

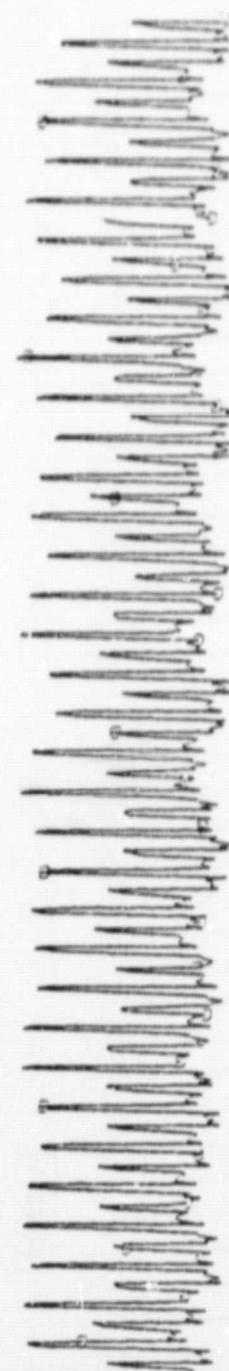
RPM



PROBE 2

long spike= 0.0029 in. avg.

short spike= 0.0020 in. avg.



PROBE 1

.005 sec.

12800 / SEC.

PP 3-13 Y 05-21-80

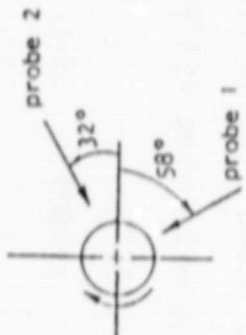
run 373 80% Ngg

mech. speed 45,450 rpm

engine oil inlet 154°F

T1 54°F.

T5 1648°F.



rear view - turbine end

FIGURE 71

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time

Steady State 90% Ngg

PP 3-13 Y 05-21-80
run 375 90% Ngg
mech. speed 51,160 rpm
engine oil inlet 154°F

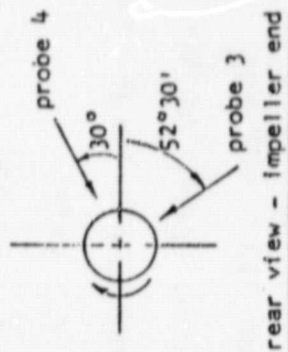
T₁ 55°F.

T₅ 1729°F.

PROBE 4

splike= 0.0024 in. avg.

FIGURE 7m



PROBE 3

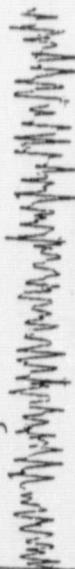
.005 sec.

12800 / SEC.

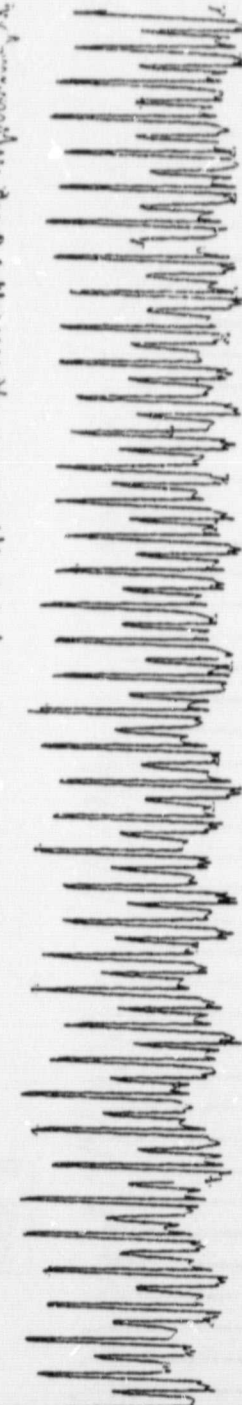
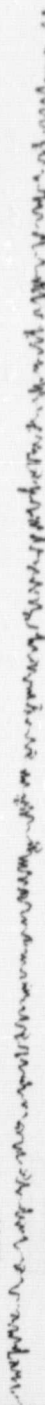
ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time
Steady State 90% Ngg

T₅



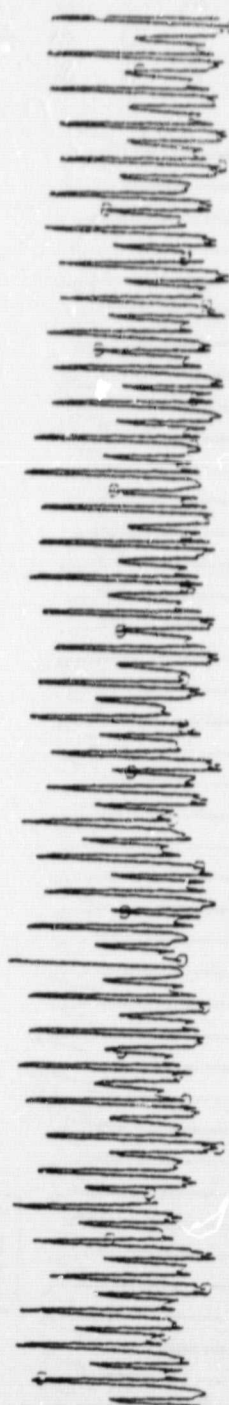
RPM



PROBE 2

long spike= 0.0029 in. avg.

short spike= 0.0020 in. avg.



PROBE 1

.005 sec.

12800 / SEC.

FIGURE 7n

PP 3-13 Y 05-21-80

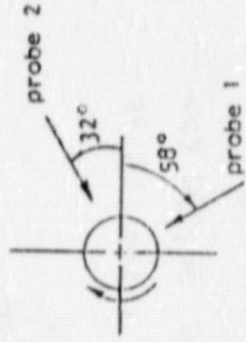
run 375 90% Ngg

mech. speed 51,160 rpm

engine oil inlet 154°F

T₁ 55°F.

T₅ 1729°F.



rear view - turbine end

3000 00 3060 00 3120 00 3180 00 3240 00 3300 00 3360 00 3420 00 3480 00 3540 00 3600 00 3660 00 3720 00 3780 00

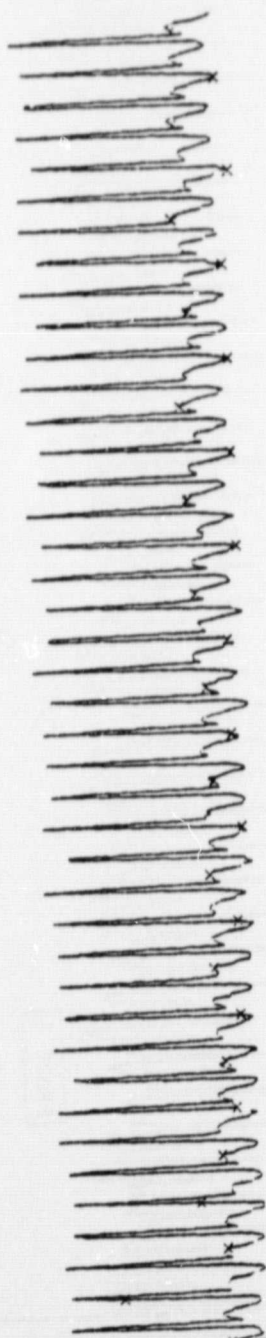
TIME

ROTOR SHAFT DYNAMICS TESTS

Displacement vs. Time
Steady State 100% Ngg

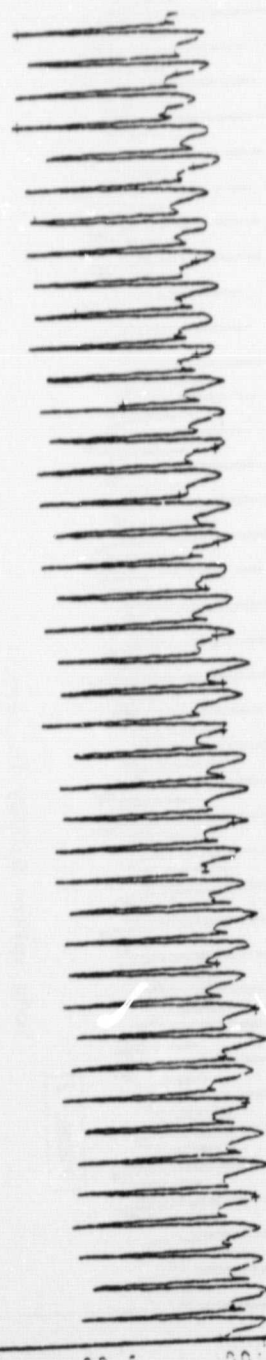
PP 3-13 Y 05-21-80
run 377 100% Ngg
mech. speed 56,930 rpm
engine oil inlet 153°F

T₁ 56°F.
T₅ 1821°F.



spike = 0.0024 in. avg.

PROBE 4



PROBE 3

0.005 sec.

12800 / SEC.

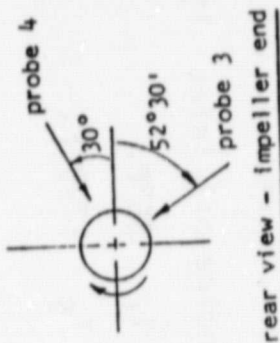
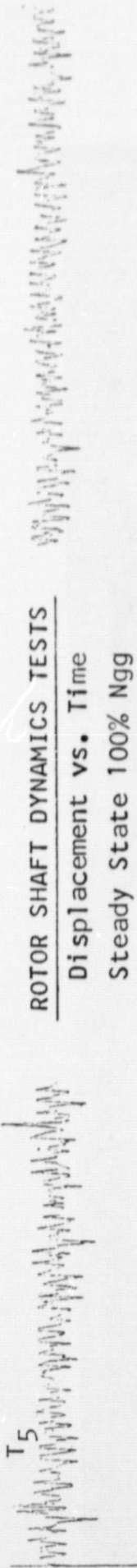


FIGURE 70



(SEE NOTE ON SPIKES)



PROBE 2

long spike= 0.0029 in. avj.

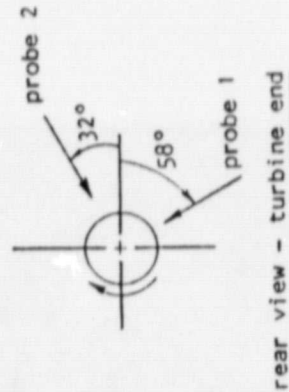
short spike= 0.0020 in. avj.

PP 3-13 Y 05-21-80
 run 377 100% Ngg

mech. speed 56,930 rpm
 engine oil inlet 153°F

T₁ 56°F.

T₅ 1821°F.



PROBE 1

0.005 sec.

12800 / SEC.

FIGURE 7p

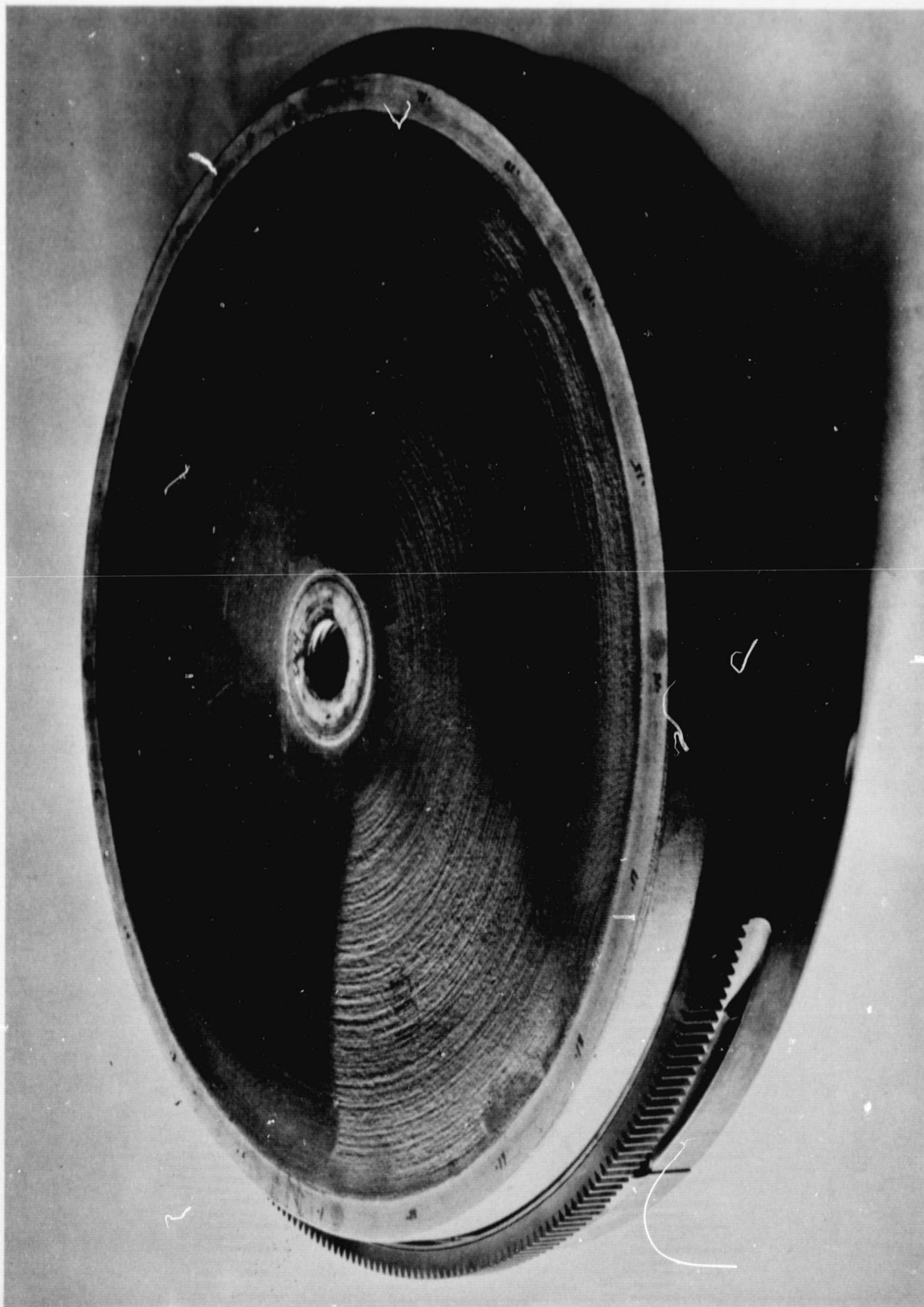


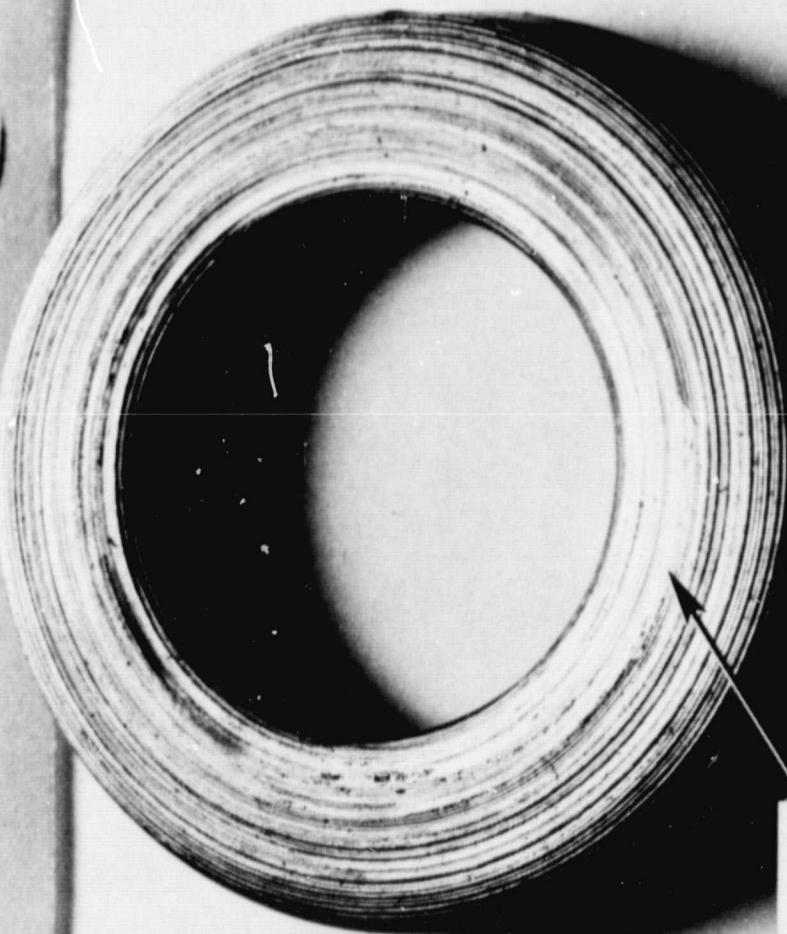
FIGURE 8a

GLAZED REGENERATOR CORE (TYPICAL)

RPZ-3 NASA LEWIS

THRUST BEARING

FROM TO RETROFIT (121-80)



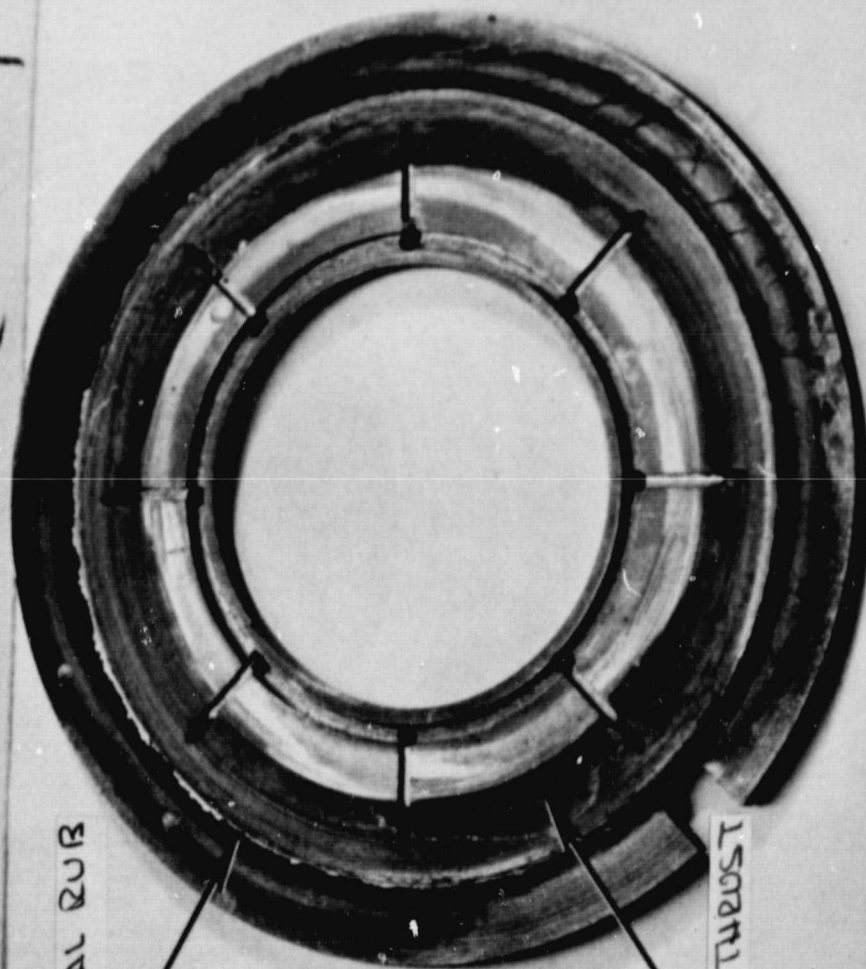
THRUST FACE COMPLETELY
WORN

FIGURE 8b

PP 2-3 NASA-LEWIS
ANTI-THRUST BRG

PRIOE TO RETROFIT (1-21-80)

LOCAL LIGHT PERIPHERAL RUB



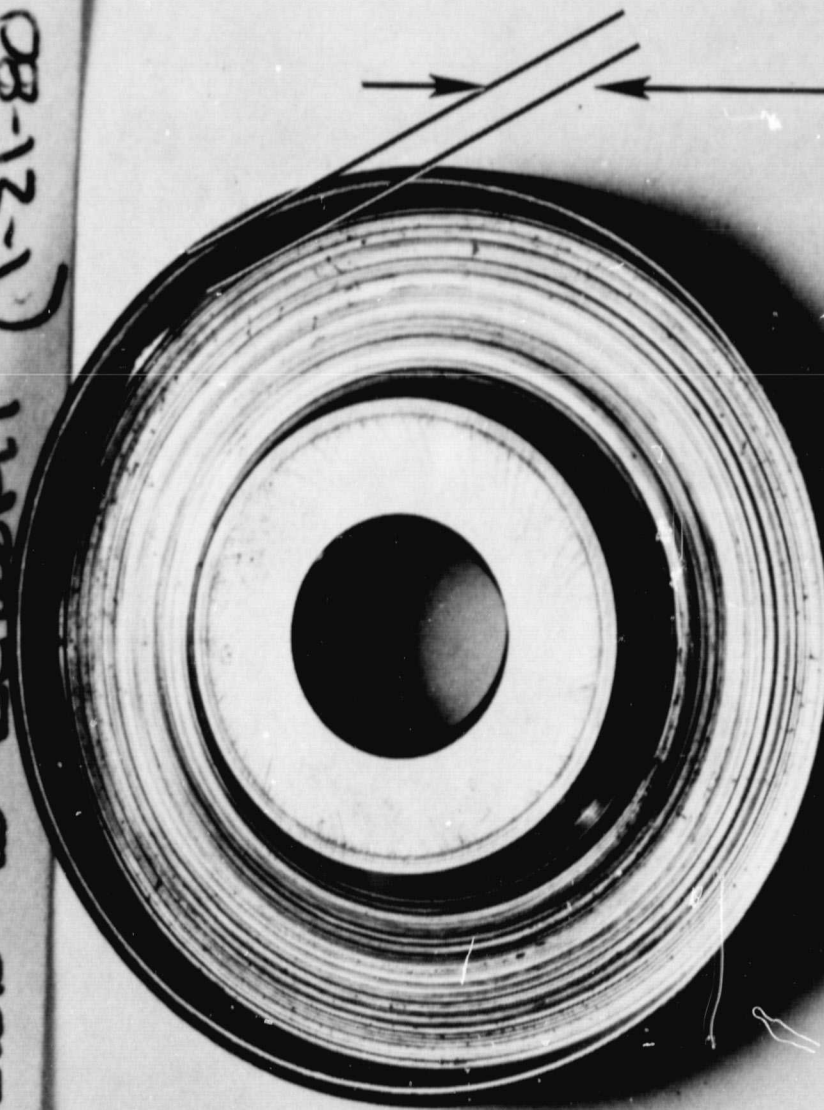
DISCOLORATION OF THRUST
FACE

ENGINE 3, FAILED ANTI-THRUST BEARING

FIGURE 8c

PP2-3 NASA LEWIS
THRUST PLATE

BEFORE TO REPAIR (1-21-80)



THRUST FACE WIDTH 1/1.5 MM

ENGINE 3, FAILED THRUST PLATE

FIGURE 8d

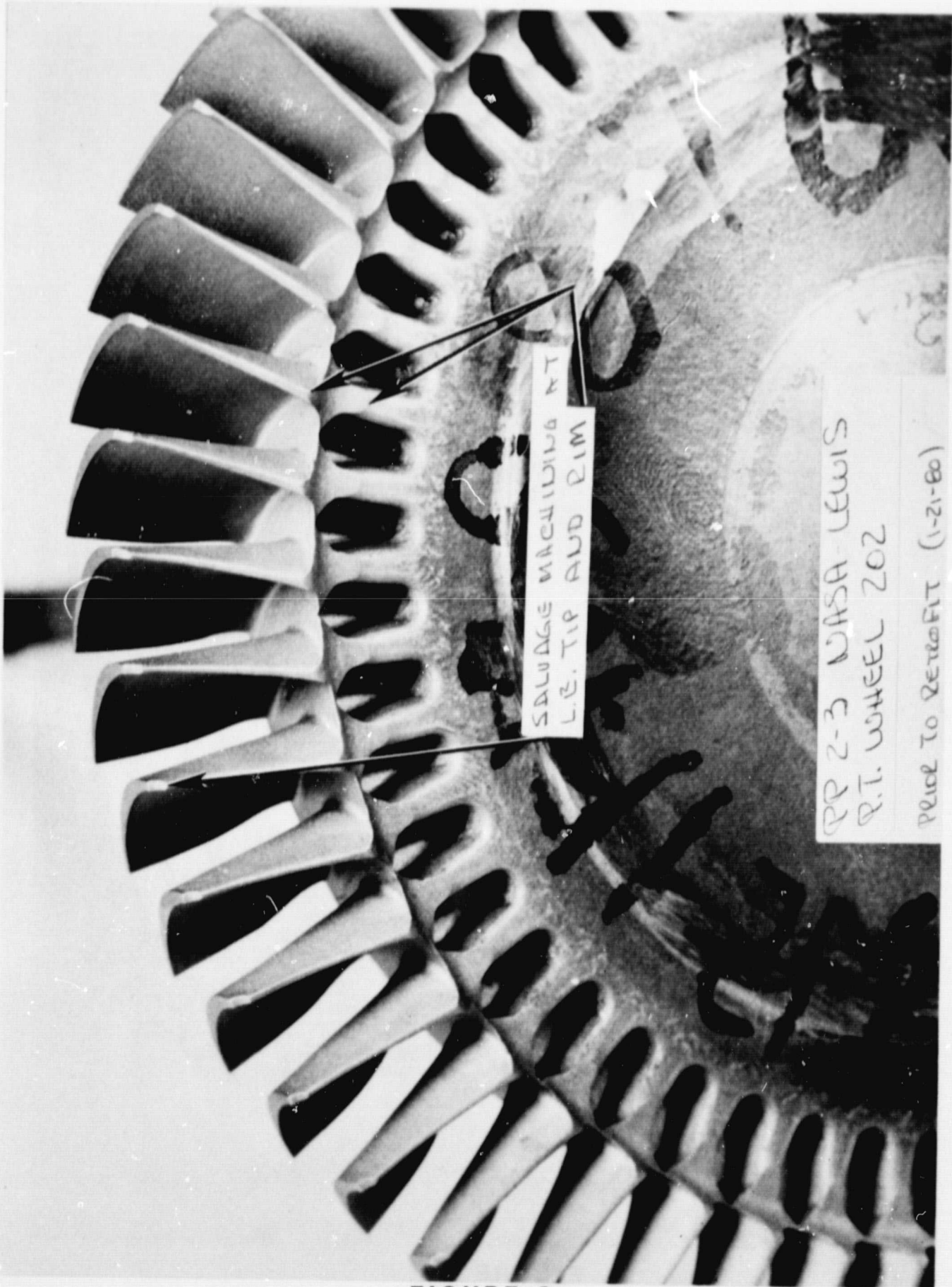


FIGURE 8.

ENGINE 3, POWER TURBINE ROTOR REPAIRS

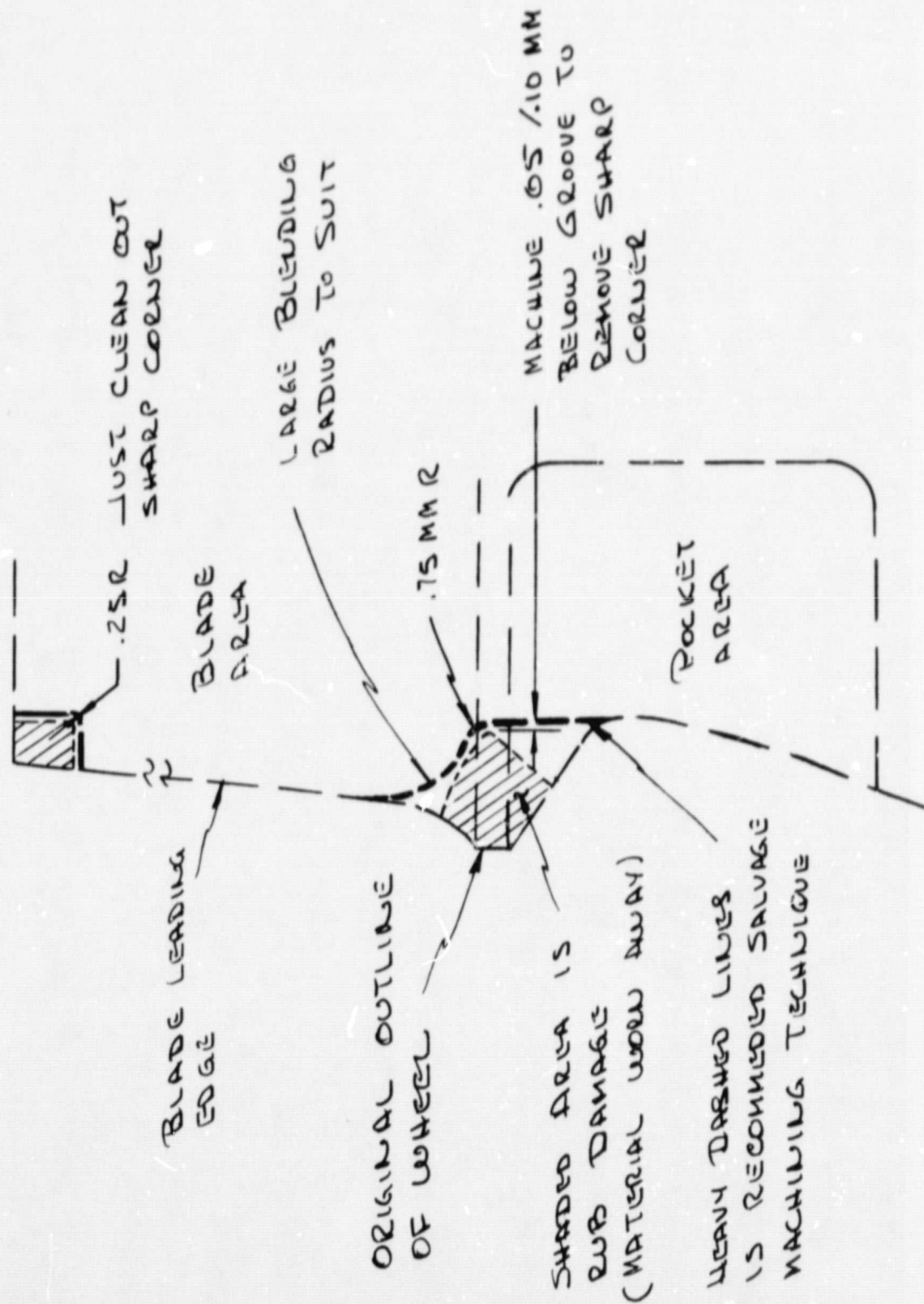


FIGURE 9

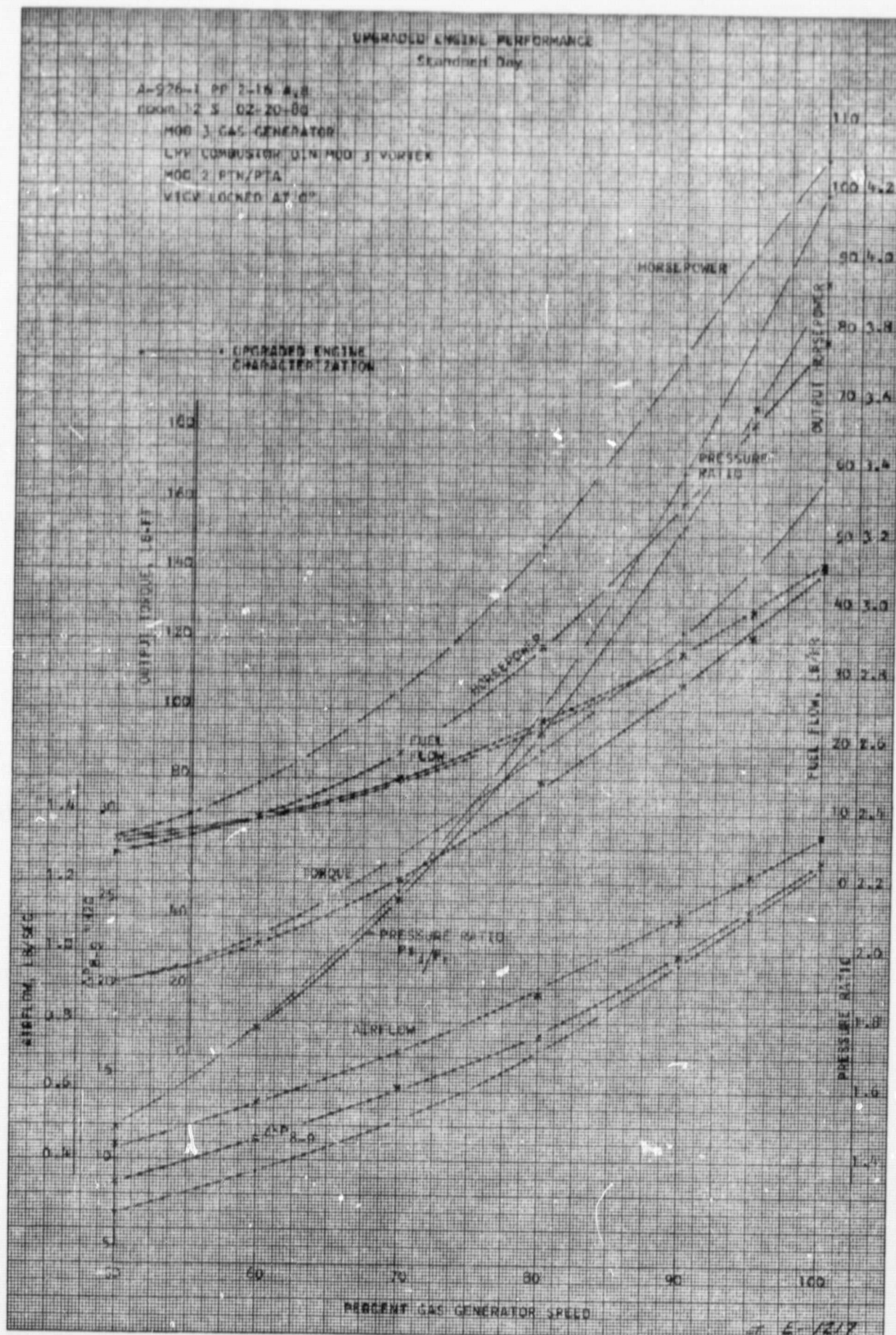


FIGURE 10

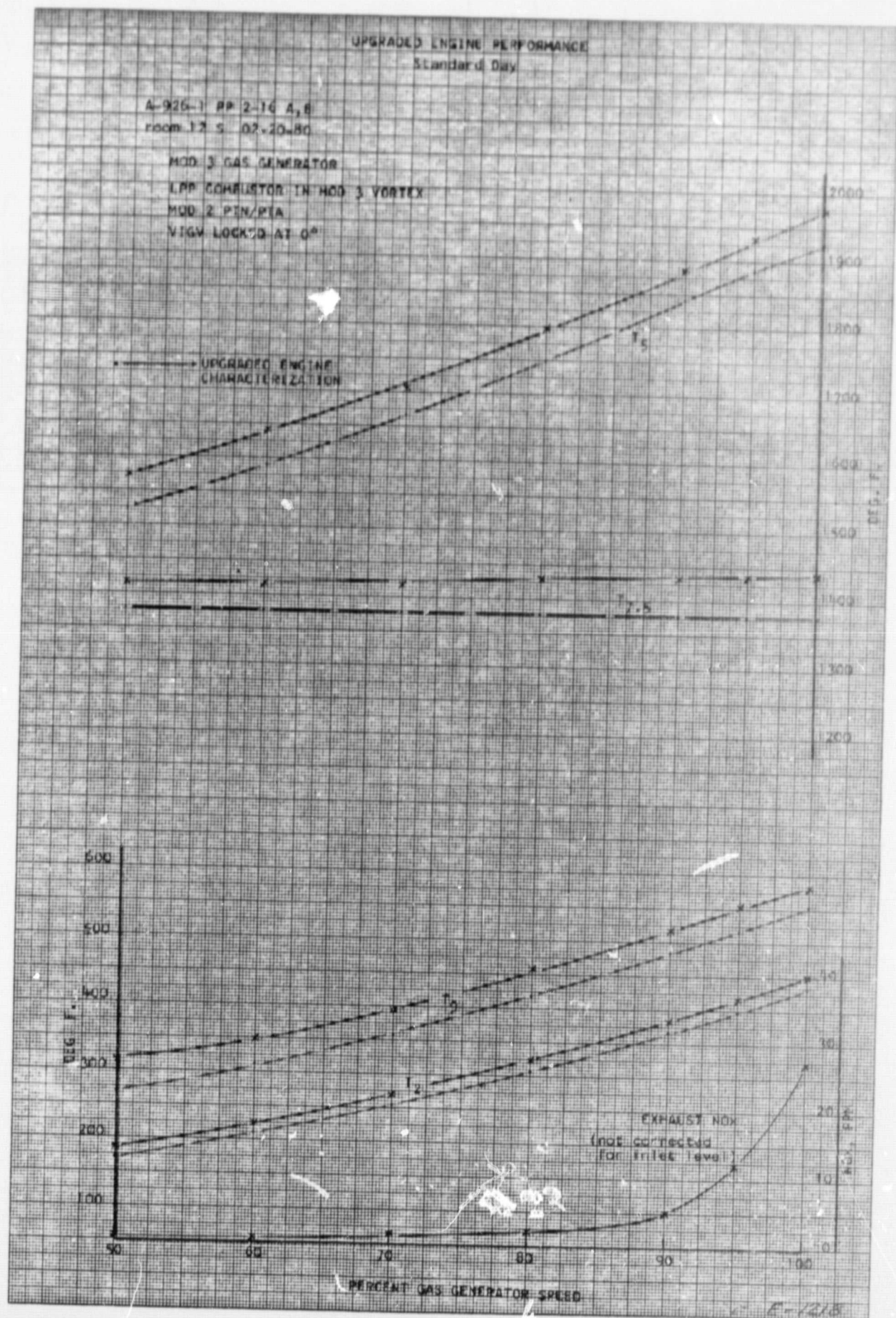


FIGURE 11

SUPPORT TO DOE
SERVICE: GAS TURBINE VEHICLES
WASHINGTON D.C. AREA
NOVEMBER 79 - JANUARY 81

DATE	D.O.	LOCATION	PROBLEM	CORRECTIVE ACTION	VEHICLE
Dec. 17	7	901 Saigon Rd. McLean, Virginia Home of R. Schulz	No Start Condition.	Replace Start Cycle Safety Circuit	B-3, 1973 Plymouth
Feb. 20	7	Silver Spring Chrysler-Plymouth Dealership Silver Spring, Md.	No Start Condition.	Replace Start Cycle Safety Circuit	B-3, 1973 Plymouth
July 1	7	Silver Spring Chrysler-Plymouth Dealership Silver Spring, Md.	Quarterly Routine Maintenance.	Inspect Combustor, Fuel Nozzle, Regenerator Cores and Turbine Wheel. (Replace Combustor Due to Fatigue Cracks) Road Match.	B-3, 1973 Plymouth
July 17	7	Silver Spring Chrysler-Plymouth Dealership Silver Spring, Md.	Alternator Not Charging At Idle With A/C On.	Replace Alternator and Voltage Regulator.	B-3, 1973 Plymouth
Nov. 18	16	Silver Spring Chrysler-Plymouth Dealership Silver Spring, Md.	Under-Shoot and Smoke on Cold Starts.	Replace Fuel Filter and Inspect Combustor Assembly, Fuel and Air Systems. Problem not Resolved	U-2, 1976 Dodge Aspen
Dec. 11	21	Silver Spring Chrysler-Plymouth Dealership Silver Spring, Md.	Under-Shoot and Smoke on Cold Starts.	Return to Detroit. Apply Instrumentation to Vehicle For Further Check Out. Replace Fuel Mixture. Correct Binding Problem in P.T.N. Actuator Adaptor.	U-2, 1976 Dodge Aspen

FIGURE 12

**SUPPORT TO DOE
EXHIBITS, DISPLAYS, DEMONSTRATIONS
OCTOBER 79 - JANUARY 81**

DATE	D.O.	LOCATION	PURPOSE	VEHICLES/DISPLAYS
Oct. 23-25	1	Hyatt Regency Hotel Dearborn, Michigan	Coordination Meeting Support Ride/Drive Demonstration	U-1, 1976 Dodge Aspen U-2, 1976 Dodge Aspen U-3, 1977 Chrysler Lebaron
Nov. 1-25	4	Daytona International Speedway Daytona Beach, Florida	Display and Demonstration for International Motor Sports Assn.	U-2, 1976 Dodge Aspen U-3, 1977 Chrysler Lebaron
Feb. 1-4	7	Daytona International Speedway Daytona Beach, Florida	Display and Demonstration for International Motor Sports Assn.	U-2, 1976 Dodge Aspen U-3, 1977 Chrysler Lebaron
Feb. 13-18	7	Daytona International Speedway Daytona Beach, Florida	Display and Demonstration for NASCAR	U-2, 1976 Dodge Aspen U-3, 1977 Chrysler Lebaron
March 3-11	11	Exhibit Hall Cleveland, Ohio	Support to NASA	U-2, 1977 Chrysler Lebaron Expanded Engine Display
March 20-30	13	Exhibit Hall Cleveland, Ohio	Support to NASA	U-3, 1977 Chrysler Lebaron
April 14-18	14	Hyatt Regency Hotel Dearborn, Michigan	5th. Automotive Symposium Ride/Drive Demonstration	U-2, 1976 Dodge Aspen U-3, 1977 Chrysler Lebaron
May 27-31	15	Sacramento, California	1st. Energy and Transportation Fair	U-3, 1977 Chrysler Lebaron
Aug. 8-11	15	Shopping Malls in Ames and Council Bluffs, Iowa	Support to Congressman Tom Harkin Display and Demonstration	U-2, 1976 Dodge Aspen
Sept. 29- Oct. 1	19	Forrestal Bldg. and Rayburn House Office Bldg. Washington, D.C.	Ride/Drive Demonstration for DOE and Congressman Tom Harkin	U-2, 1976 Dodge Aspen U-3, 1977 Chrysler Lebaron
Oct. 11-15	19	Holiday Inn Surfside Daytona Beach, Florida	Support to DOE at the Daytona Beach Community College National Confer- ence For Automotive Educators	U-3, 1977 Chrysler Lebaron
Nov. 12-16	19	Cobo Hall Detroit, Michigan	Support to DOE at Michigan Energy Expo 80	U-3, 1977 Chrysler Lebaron
Nov. 10-13	MOD-MO15 Interim Contract	Hyatt Regency Hotel Dearborn, Michigan	Coordination Meeting Support Ride/Drive Demonstration	U-4, 1980 Dodge Mirada Chrysler/Williams ACT-102 Mock Up w/Display Boards

FIGURE 13

VEHICLE USAGE SUMMARY

1979 - 1981

<u>MONTH</u>	<u>VEHICLE NO.</u>	<u>HOURS</u>	<u>MILES</u>	<u>STARTS</u>	<u>COMMENTS</u>
Oct.	U-1 385	55.3	546.5	682	
Nov.		55.3	546.5	683	
Dec.		55.6	546.9	706	
Jan.		56.1	547.4	722	
Feb.		56.4	547.4	725	
March		56.5	547.4	726	
April		57.1	547.4	747	
May	U-2 386	57.6	547.4	750	
June		57.6	547.4	750	Deactivated vehicle; Removed E-2.
Oct.	U-2 386	380.0	5556.9	3362	Electric clutch replaced
Nov.		388.5	5610.	3445	PTN actuator req. service.
Dec.		391.4	5627.4	3475	Vehicle chassis sustained damage Repaired chassis structural damage; serviced gas generator
Jan.		395.5	5641.5	3502	
Feb.		404.4	5698.5	3568	
March		407.7	5749.9	3592	
April		424.1	6088.1	3677	Repainted vehicle
May		426.2	6105.1	3693	
June		429.3	6145.5	3706	
July		435.6	6264.3	3734	
Aug.		442.5	6493.7	3793	
Sept.		448.8	6598	3861	Shipped vehicle to Wash. D.C.
Oct.		454.7	6683	3883	
Nov.		461.6	6819	3946	Req'd. service call; control problem; cold start
Dec.		464.4	6828	3975	Return to Detroit; diagnose control problem
Jan.		470.6	6893	4001	
Oct.	U-3 649	60.6	279.	924	
Nov.		60.6	279.	924	
Dec.		60.8	*-	*-	
Jan.		61.6	-	940	Repaired intake duct/boot
Feb.		67.9	307	1034	Repaired chassis structural damage, cooler, fan mounts
March		68.8	308.	1104	
April		70.4	309	1151	
May		-	-	-	Repainted vehicle; shipped to Sacramento, Calif.
June		-	-	-	Display/demonstration, Sacramento, Calif.
July		-	-	-	
Aug.		-	-	-	
Sept.		75.6	321	1291	Returned to Detroit; repaired; shipped to Wash. D.C.
Oct.		79.4	332	1348	Shipped from Wash. D.C. to Daytona Beach, Fl.; returned to Det.
Nov.		80.1	332	1376	Display at Mich. Energy Expo 80
Dec.		80.1	332	1379	
Jan.		80.4	332	1384	

* odometer, counter inoperative

FIGURE 14a

VEHICLE USAGE SUMMARY

1979 - 1981

<u>MONTH</u>	<u>VEHICLE NO.</u>	<u>HOURS</u>	<u>MILES</u>	<u>STARTS</u>	<u>COMMENTS</u>
Aug.	U-4 469	-	53.0	-	Vehicle modification complete
Sept.		57.9	53.0	768	Note: hrs, starts, are from vehicle U-1, Engine 2
Oct.		67.8	99.0	845	Prepared for CCM, Mod MO15 contract
Nov.		82.5	313.0	896	Demonstration at CCM Hyatt Regency funded by MOD MO15 contract
Dec.		87.5	324.0	923	Installed updated car comfort systems
Jan.		89.6	324.0	941	
Sept.	B-3 671	1025.4	21659	5618	Baseline vehicle, in storage @ Silver Spring Dodge Inc., Silver Spring, Md.
Oct.		1026.6	21670	5625	
Nov.		1026.6	21670	5626	
Dec.		1026.6	21670	5632	Reactivated vehicle
Jan.		1026.6	21670	5633	

FIGURE 14b

BASELINE VEHICLE SUMMARY

<u>CAR NUMBER</u>	<u>618 (C-2)</u>	<u>667 (B-2)</u>	<u>671 (B-3)</u>
Body Style	1973 Dodge Coronet 4 Door	1973 Plymouth Satellite 4 Door	1973 Plymouth Satellite 4 Door
Engine Number	101-408AM	404-413W	403-422I
Delivered HP	150	N/A	N/A
Curb Weight	4396	4436	4441
Axle Ratio	2.76	2.76	2.76
Tires	GR78-15 Poly	HR78-14	GR78-15 Poly
Odometer	11842.2	17774	21670.2
Run Time Hours	714.6	734.6	1026.6
Starter Engagements		3901	5633
Combustor	Droplet Diffusion	Droplet Diffusion	Droplet Diffusion
Fuel	Unleaded Gasoline	Diesel/Unleaded Gasoline	Diesel/Unleaded Gasoline
Special Equipment	Ultra Control PAC-250 Modine Oil Cooler	P/S Oil to Power Throttle Cloth Interior	Nexdamp Intake Duct P/S Oil to Power Throttle
Current Activity		Chrysler Engineering Out of Service	Support to DOE @ Washington, D.C.
Future Activity	Corporate Demo	Support to DOE	Support to DOE

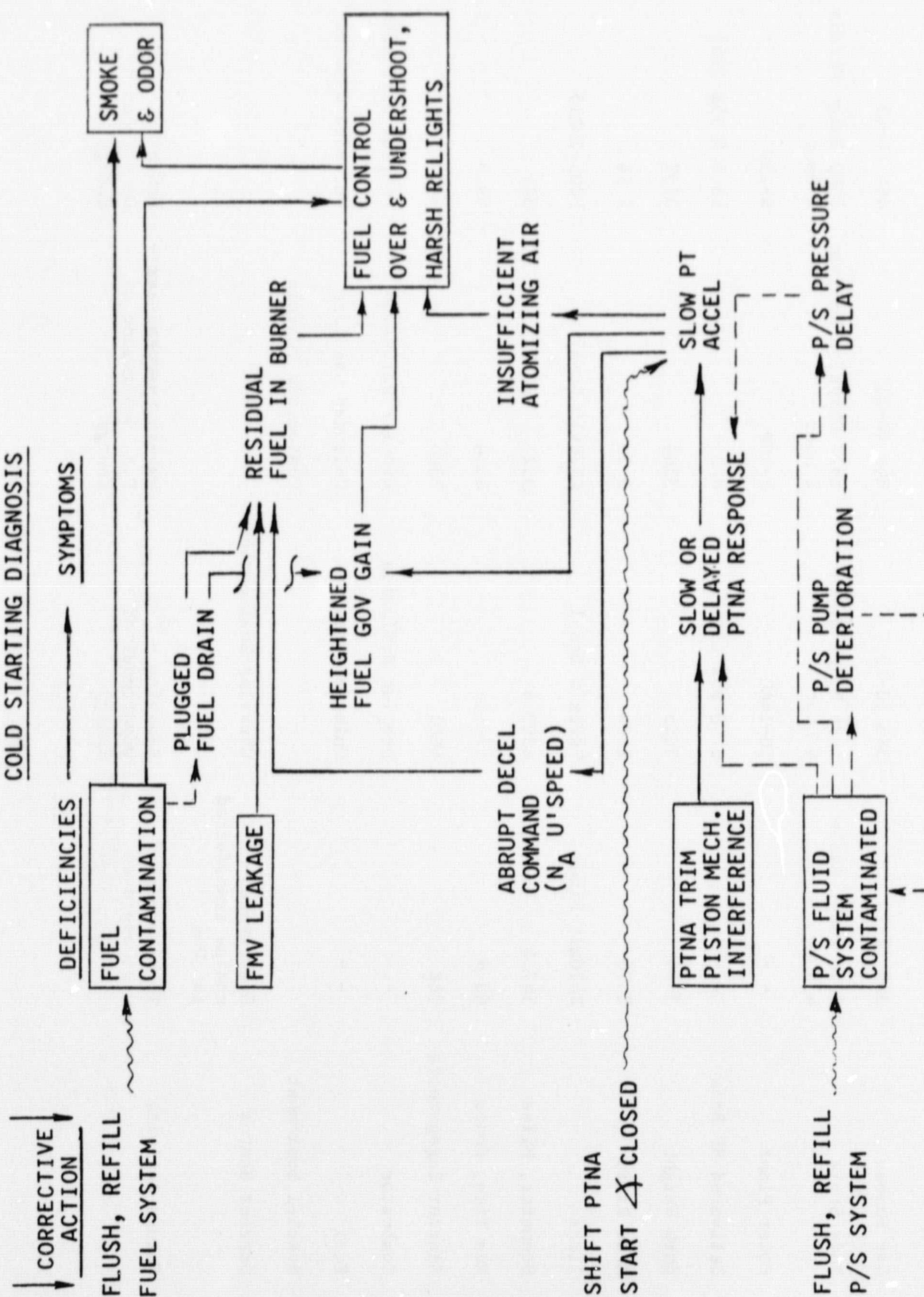
FIGURE 15

UPGRADE VEHICLE SUMMARY

Car Number	385 (U-1)	386 (U-2)	649 (U-3)	469 (U-4)
Body Style	1976 Dodge Aspen 4 Door	1976 Dodge Aspen 4 Door	1977 Chrysler LeBaron 2 Door	1980 Dodge Mirada 2 Door
Power Plant	- -	10-14AG	8-10N	4-15N
Delivered HP Base	- -	67 @ 95% (T5)	N/A	63.5 @ 95% (T5)
Curb Weight	3766	3685	3884	3732
Axle Ratio	2.76	2.94	3.21	2.94
Tires	FR70x14 Fiber	FR78x14 Steel	GR78x15 Steel	P205-75R15
Odometer, Miles	547.4	6893.4	332	324
Run Time, Hours	63.9	470.6	80.4	89.6
Starter Engagements	768	4001	1384	941
Combustor	- -	Droplet Diffusion	Droplet Diffusion	Droplet Diffusion
Fuel	- -	Unleaded Gasoline	Unleaded Gasoline	Unleaded Gasoline
Special Equipment			Customized Vehicle	
Current Status	Deactivated- engine transferred to U-4	Chrysler-Engineering		
Future Activity	To be scrapped upon approval	Exhibits - U.S. Department of Energy	Public interest car - U.S. Department of Energy	Exhibits - U.S. Department of Energy

FIGURE 16

COLD STARTING DIAGNOSIS





VEHICLE U4, 1980 DODGE MIRADA

FIGURE 18a



ENGINE INSTALLATION - VEHICLE U4, 1980 DODGE MIRADA

FIGURE 18b

CONTROL SYSTEM FAMILIARIZATION SCHEDULE

UPGRADED ENGINE

NASA SERVICE CONTRACT DEN 3-144

JANUARY 22-24, 1980

I CONTROL SYSTEM OVERVIEW AND ENGINE REQUIREMENTS

1. Fuel System
2. Variable Power Turbine Nozzle System
3. Variable Inlet Guide Vane System
4. Starter System
5. Safeties

II PROGRAMMABLE ANALOG CONTROL (PAC) SYSTEM

1. Early Development (PAC 120, PAC 250)
2. Description of Electronic Control Unit (ECU)
(PAC 500)
 - Mother Board
 - Power Supply
 - Analog Input/Output Boards
 - Analog Computer (GCA Board)
 - Digital GCA Control and ROM Memory
3. Software Programming
4. Programming Hardware
 - Pin Panel
 - Prolog Prom Programmer
 - Keyboard Programmer
 - Program Printer
5. Sensors
6. Turbine Control Panel and Engine/ECU Diagnostics.

III PROGRAMMING THE PAC 500

1. Block Diagrams
2. Flow Charts
3. Analog Computing Unit (ACU) Instruction Set
4. Typical Subroutines
 - Pre-Start Timer and Open Circuit Safeties
 - Pedal Schedule
 - Gas Generator Speed Governing

FIGURE 19a

IV LABORATORY SESSION

Engine Simulation/Keyboard Demonstration
Engine Test/Prom Programming Demonstration

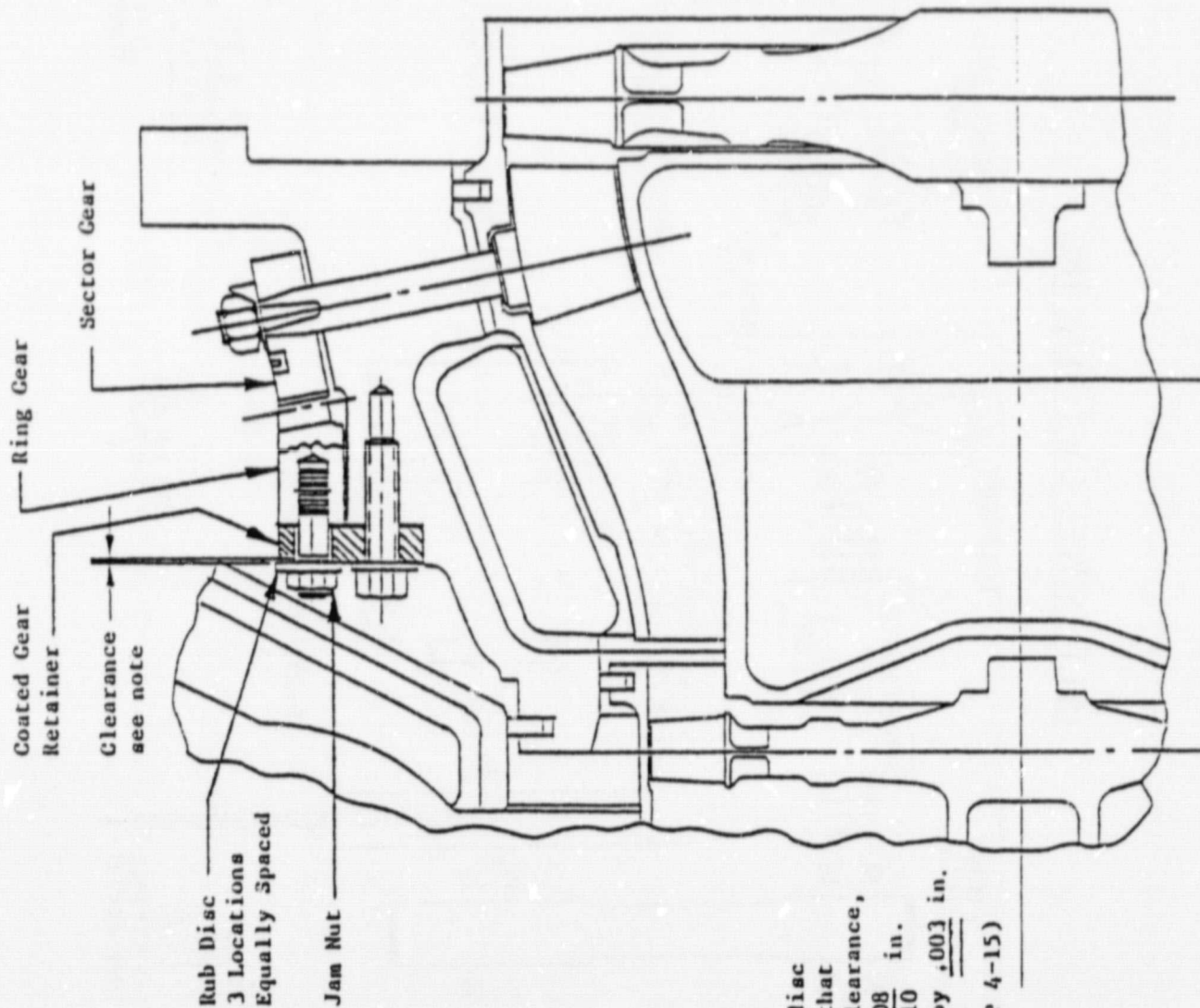
V FUTURE CONSIDERATION

1. NASA Engine Tests
2. AGT

Digital/Analog
Dedicated/Programmable
Input/Output Interface
Programmable Digital Controller - PDC
Dedicated Programmable Production Prototype

HANDOUTS

1. Control System Excerpt, A-926 Final Report, with additional notes on ECU.
2. Section 4 (Programming) of PAC User's Manual, Ultra Electronics, Inc. with sample Upgraded Engine subroutines.



NOTE: Adjust rub disc
jam nut so that
ring gear clearance,
nominally $\frac{.008}{.010}$ in.
is reduced by $\frac{.003}{.010}$ in.
(PTN -3, PP 4-15)

FIGURE 20

POWER TURBINE NOZZLE VANE MECHANISM MODIFICATION
WITH 3 RUB DISCS INSTALLED ON RING GEAR

BELT-DRIVE C V T TEST RIG

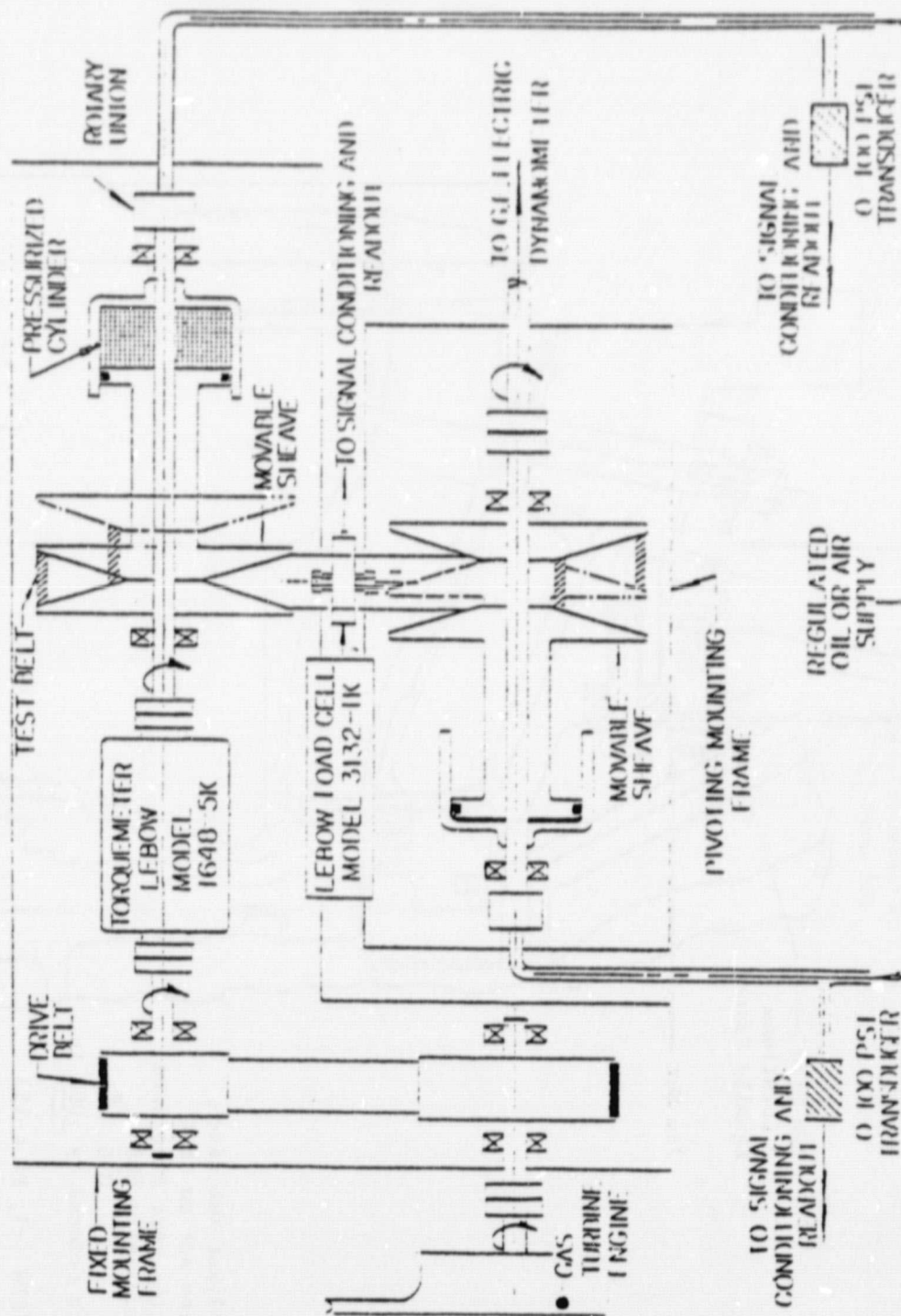


FIGURE 21

V-BELT CVT RIG TESTS

TEST POINTS

<u>No</u> <u>Ni</u>	<u>No</u>	<u>HP</u> <u>out</u>	<u>Setting</u>	<u>Specified</u> <u>λ</u> <u>Range</u>	<u>Available</u> <u>λ</u> <u>Range</u>
1.78	3200	11.0	A	.1 - .9	.1 - .6
1.00	3200	19.5	B	.2 - .9	.1 - .8
1.00	1800	11.0	C	.2 - .9	.1 - .8
.56	1800	19.5	D	.2 - .9	.2 - .8
1.78	3200	19.5	E	.2 - .9	.2 - .6
1.00	3200	34.7	F	.3 - .9	.2 - .8
1.00	1800	19.5	G	.3 - .9	.2 - .8
.56	1800	34.7	H	<u>.4 - .9</u>	<u>.3 - .8</u>
				61 Total	53 Total
				49 Total, Specified <u>and</u> Achievable	

No = Output Speed, RPM

Ni = Input Speed, RPM

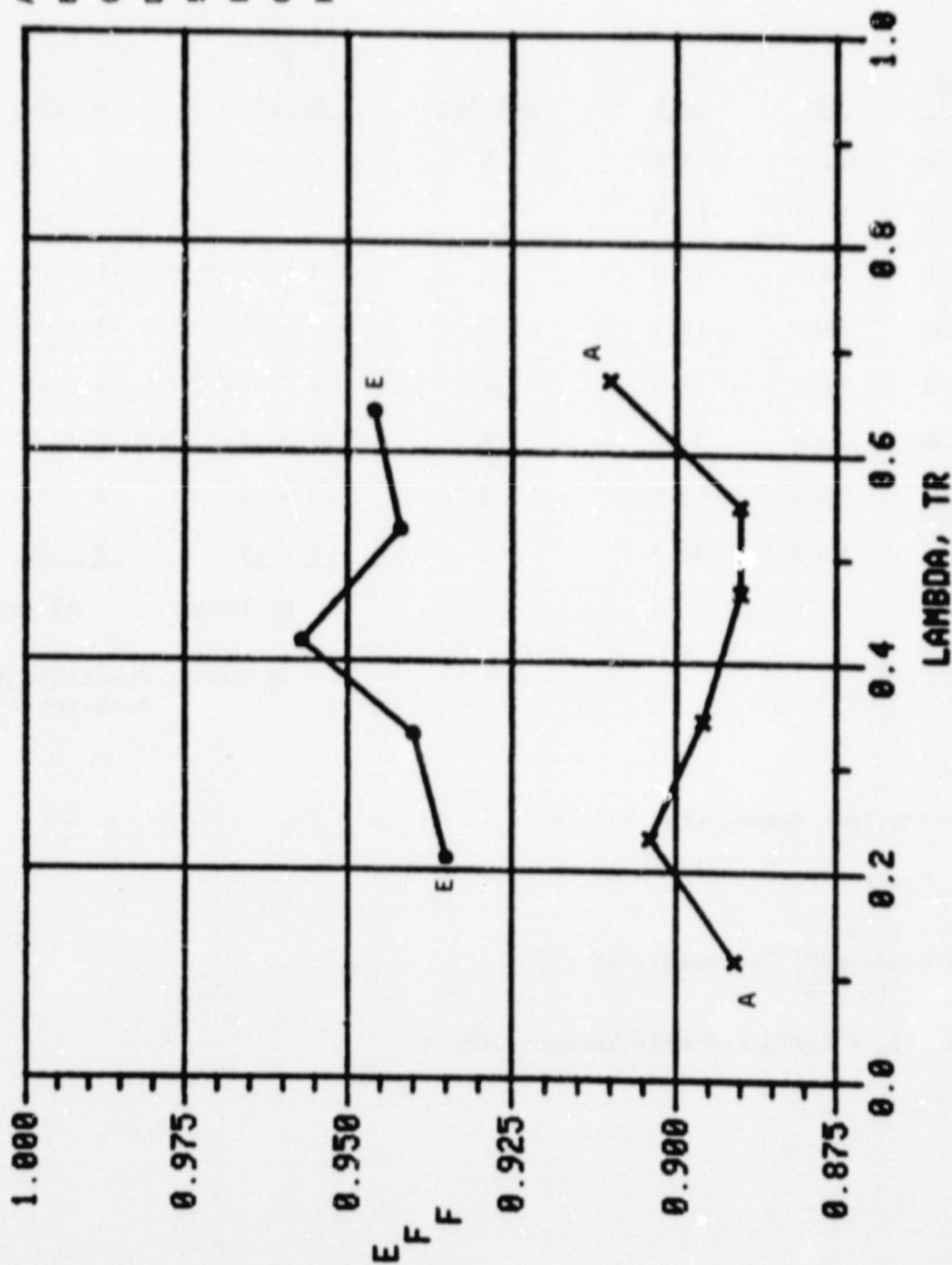
$$\lambda = \frac{T_1 - T_2}{T_1 + T_2}, \text{ increments of .10}$$

T₁, T₂ = Estimated Belt Tension Forces

FIGURE 22

BELT 4 VENDOR B 05-14-80 RUNS 61-110 11S

Setting	nominal	
	No Ni	No HP out
A x	1.78	3200
B	1.00	3200
C	1.00	1800
D	.56	1800
E o	1.78	3200
F	1.00	3200
G	1.00	1800
H	.56	1800

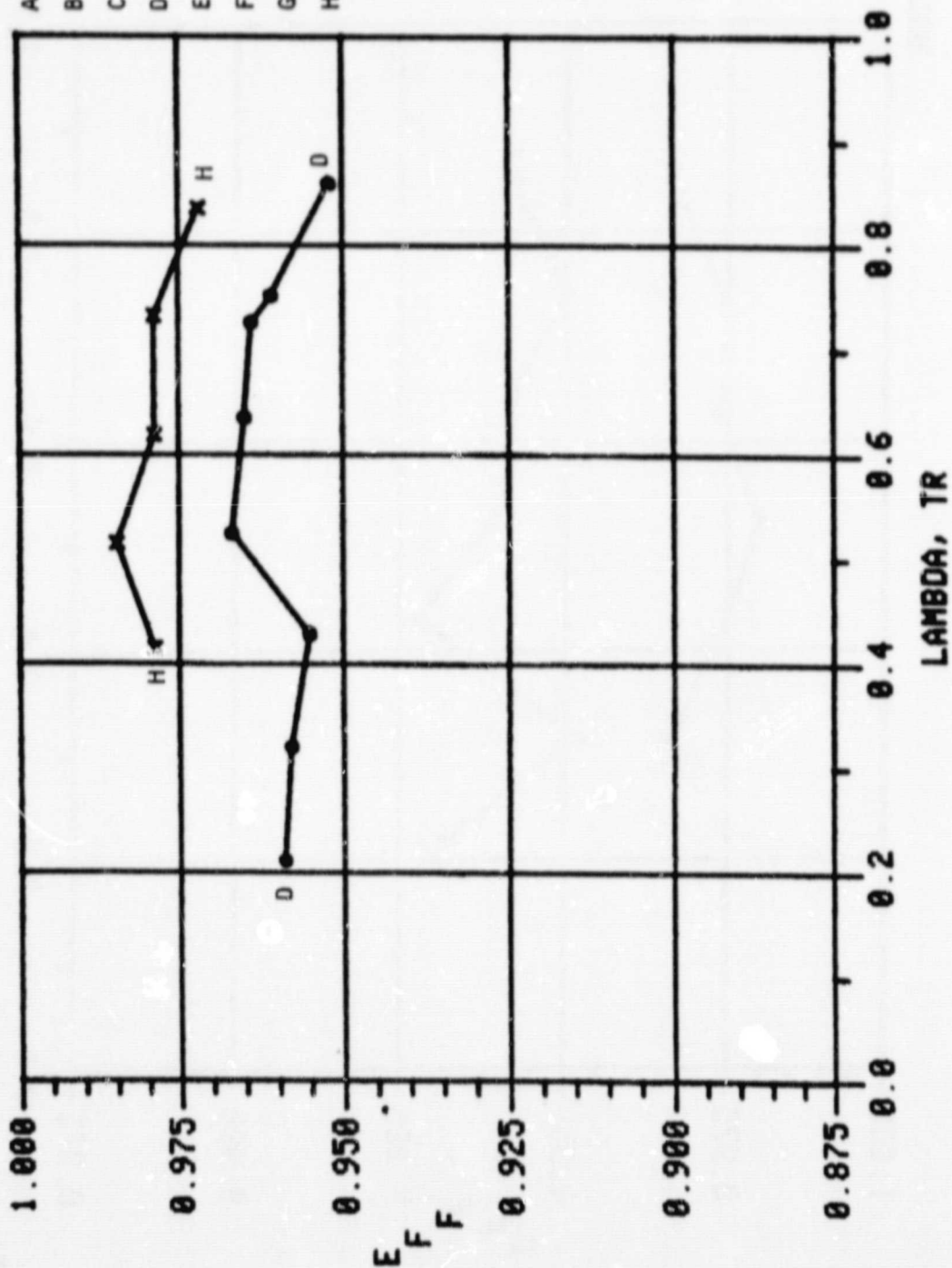


TRANSMISSION EFFICIENCY versus TRACTION RATIO
V-BELT TEST RIG
UNCORRECTED DATA

FIGURE 23a

BELT 4 VENDOR B 05-14-80 RUNS 61-110 118

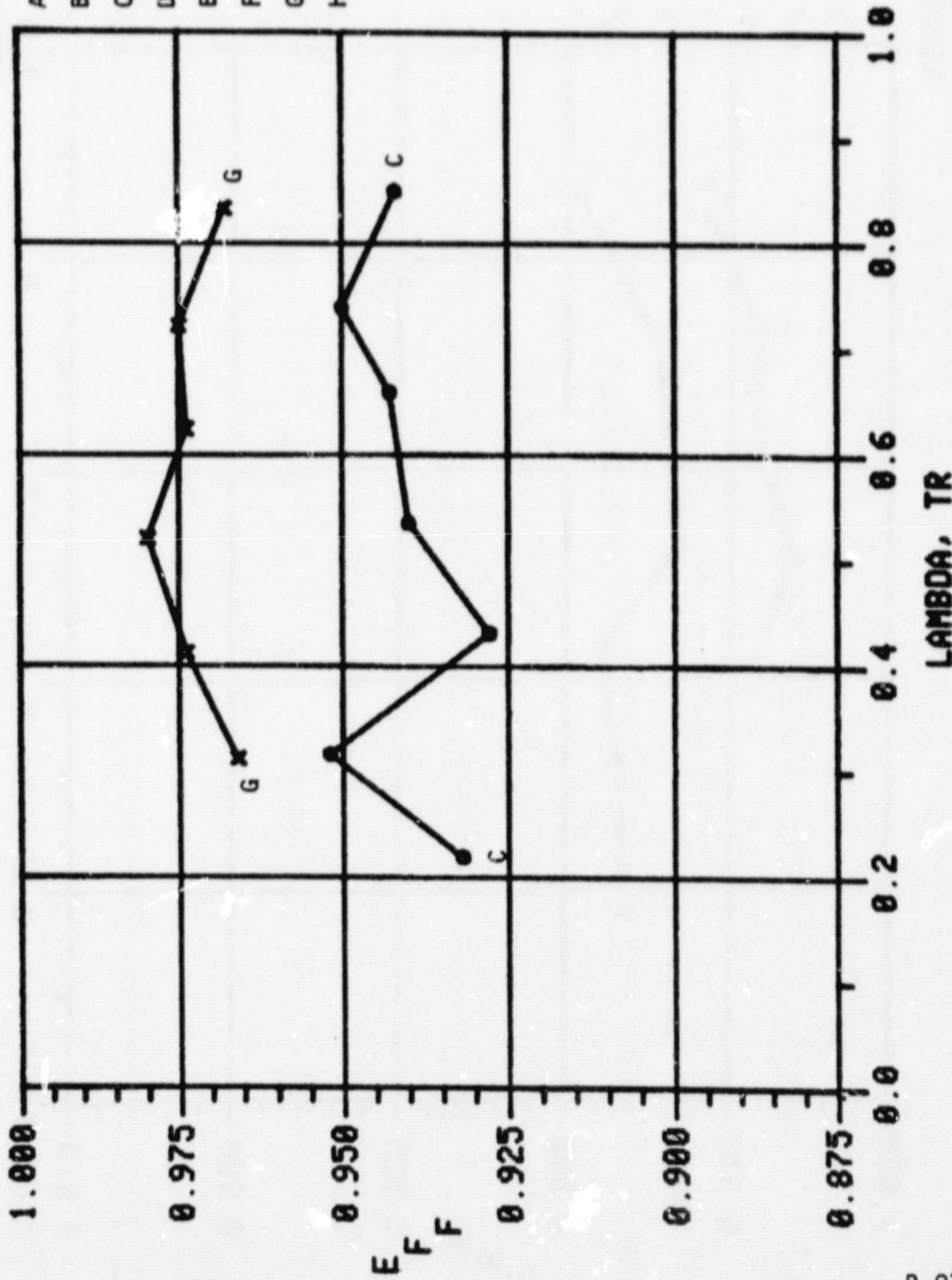
Setting	No Ni	nominal No	HP out
A	1.78	3200	11.0
B	1.00	3200	19.5
C	1.00	1800	11.0
D	.56	1800	19.5
E	1.78	3200	19.5
F	1.00	3200	34.7
G	1.00	1800	19.5
H	.56	1800	34.7



TRANSMISSION EFFICIENCY versus TRACTION RATIO
V-BELT TEST RIG UNCORRECTED DATA

FIGURE 23b

Setting	nominal	
	No. Ni	No. in Out
A	1.78	3200 11.0
B	1.00	3200 19.5
C	1.00	1800 11.0
D	.56	1800 19.5
E	1.78	3200 19.5
F	1.00	3200 34.7
G	1.00	1800 19.5
H	.56	1800 34.7



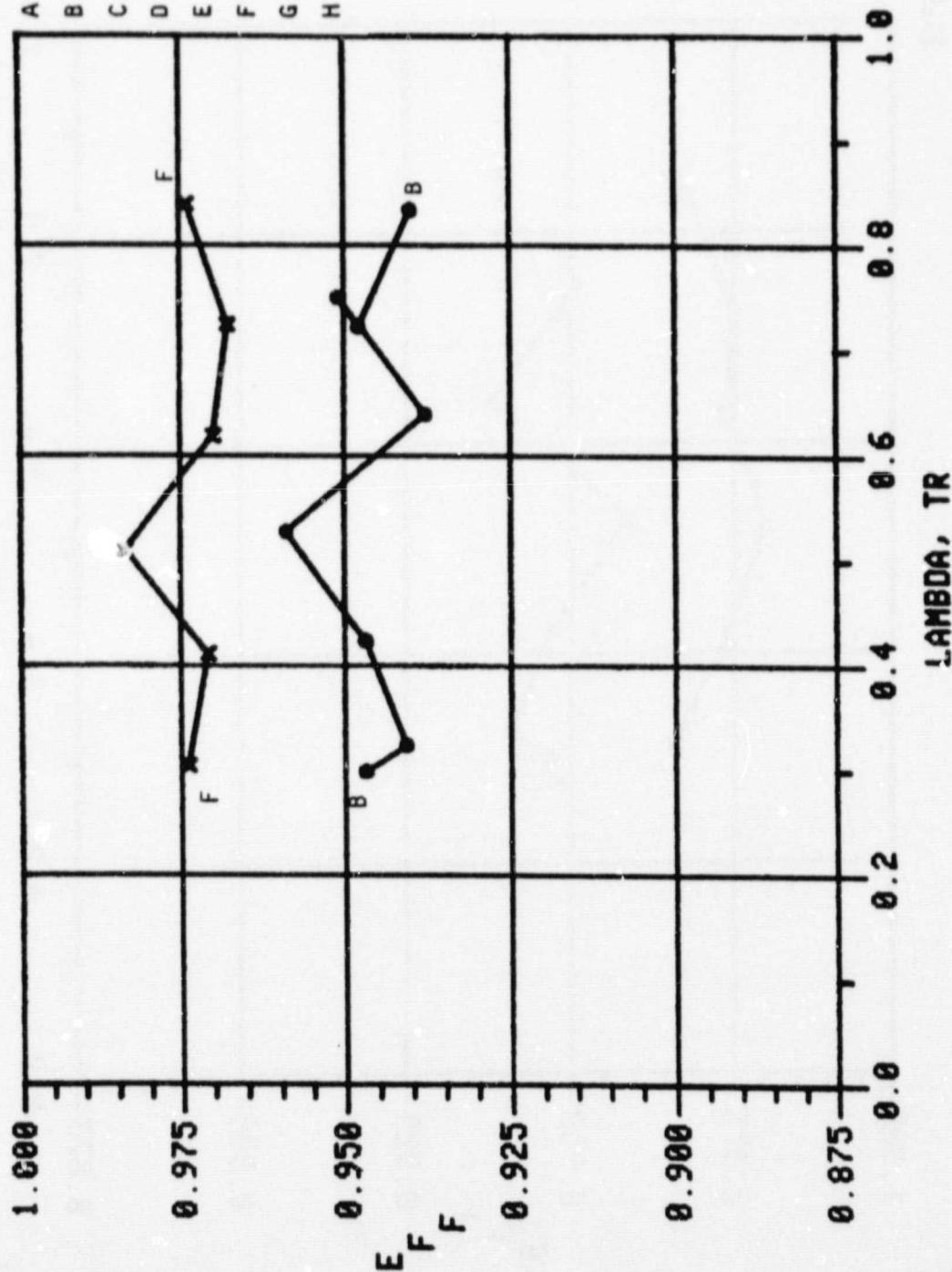
TRANSMISSION EFFICIENCY versus TRACTION RATIO
V-BELT TEST RIG UNCORRECTED DATA

R-97

FIGURE 23c

BELT 4 VENDOR B 05-14-80 RUNS 61-110 11S

Setting	nominal		
	No Ni	No	HP out
A	1.78	3200	11.0
B	1.00	3200	19.5
C	1.00	1800	11.0
D	.56	1800	19.5
E	1.78	3200	19.5
F X	1.00	3200	34.7
G	1.00	1800	19.5
H	.56	1800	34.7



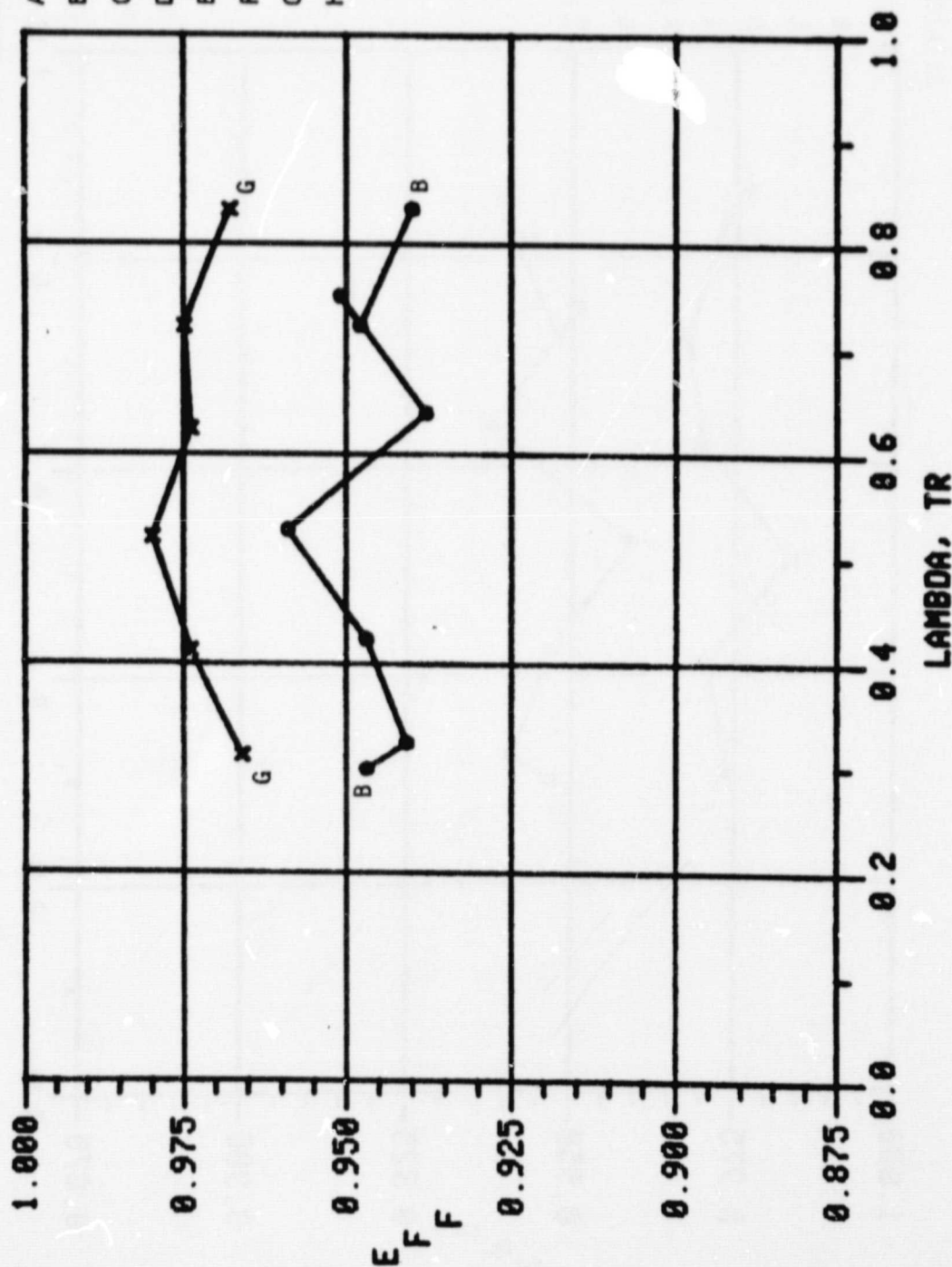
TRANSMISSION EFFICIENCY versus TRACTION RATIO
V-BELT TEST RIG
UNCORRECTED DATA

R-98

FIGURE 23d

BELT 4 VENDOR B 05-14-80 RUNS 61-110 118

Setting	nominal	
	No. Ni	No. HP out
A	1.78	3200 11.0
B	1.00	3200 19.5
C	1.00	1800 11.0
D	.56	1800 19.5
E	1.78	3200 19.5
F	1.00	3200 34.7
G	1.00	1800 19.5
H	.56	1800 34.7



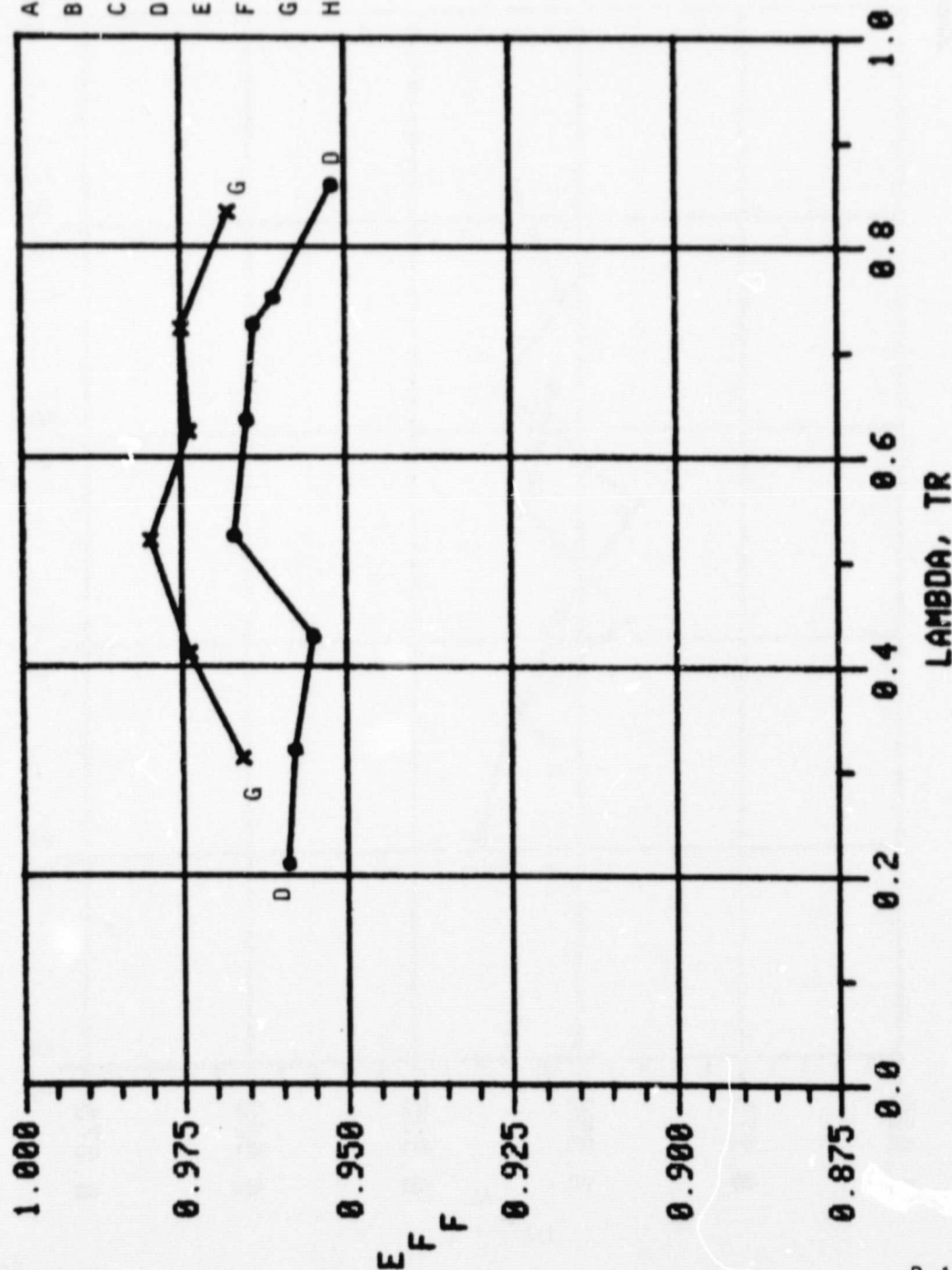
TRANSMISSION EFFICIENCY versus TRACTION RATIO
V-BELT TEST RIG
UNCORRECTED DATA

R-99

FIGURE 23e

BELT 4 VENDOR B 05-14-80 RUNS 61-110 11S

Setting	nominal	
	No Ni	HP out
A	1.78 3200	11.0
B	1.00 3200	19.5
C	1.00 1800	11.0
D	.56 1800	19.5
E	1.78 3200	19.5
F	1.00 3200	34.7
G	1.00 1800	19.5
H	.56 1800	34.7



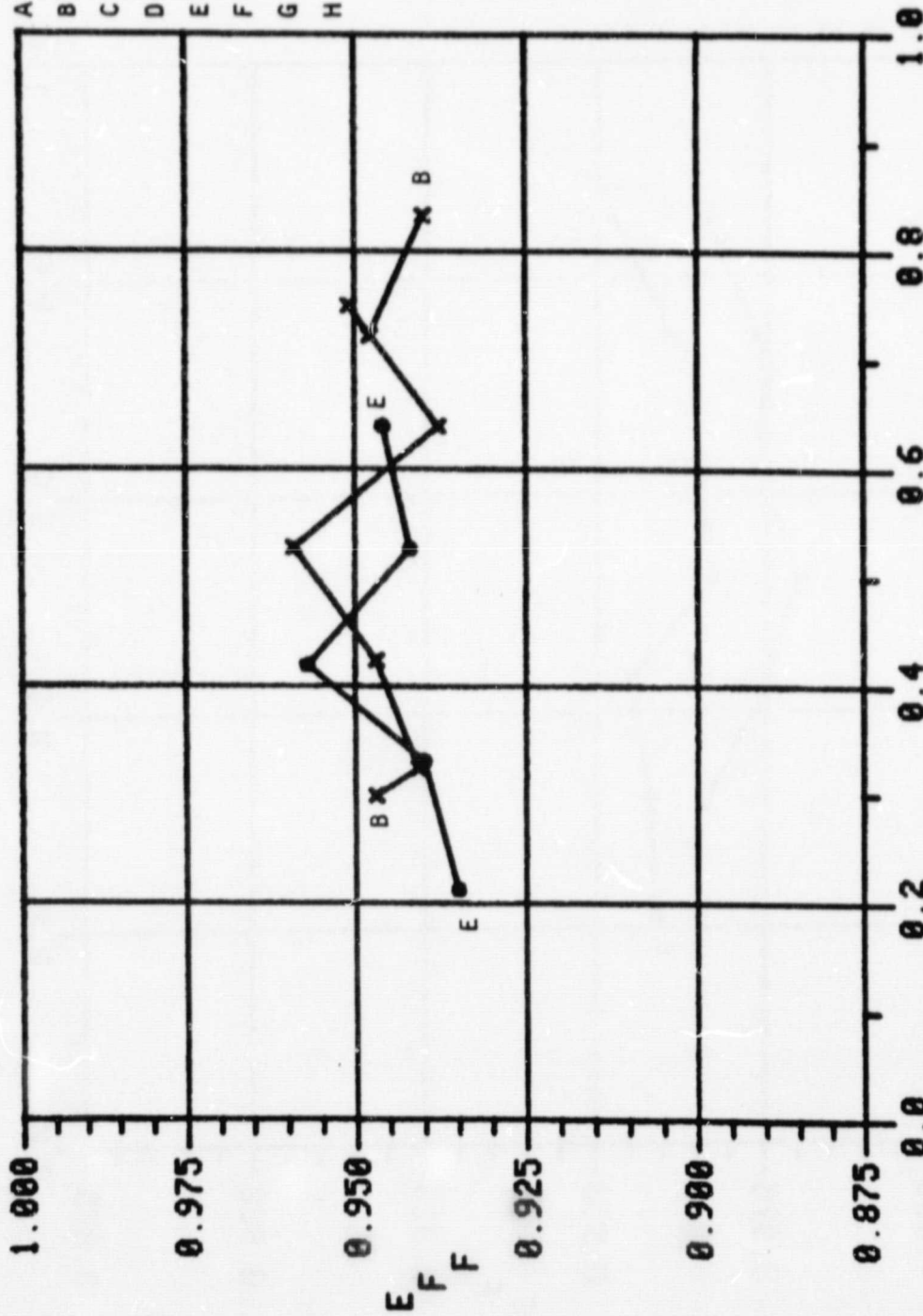
TRANSMISSION EFFICIENCY versus TRACTION RATIO
V-BELT TEST RIG UNCORRECTED DATA

R-100

FIGURE 231

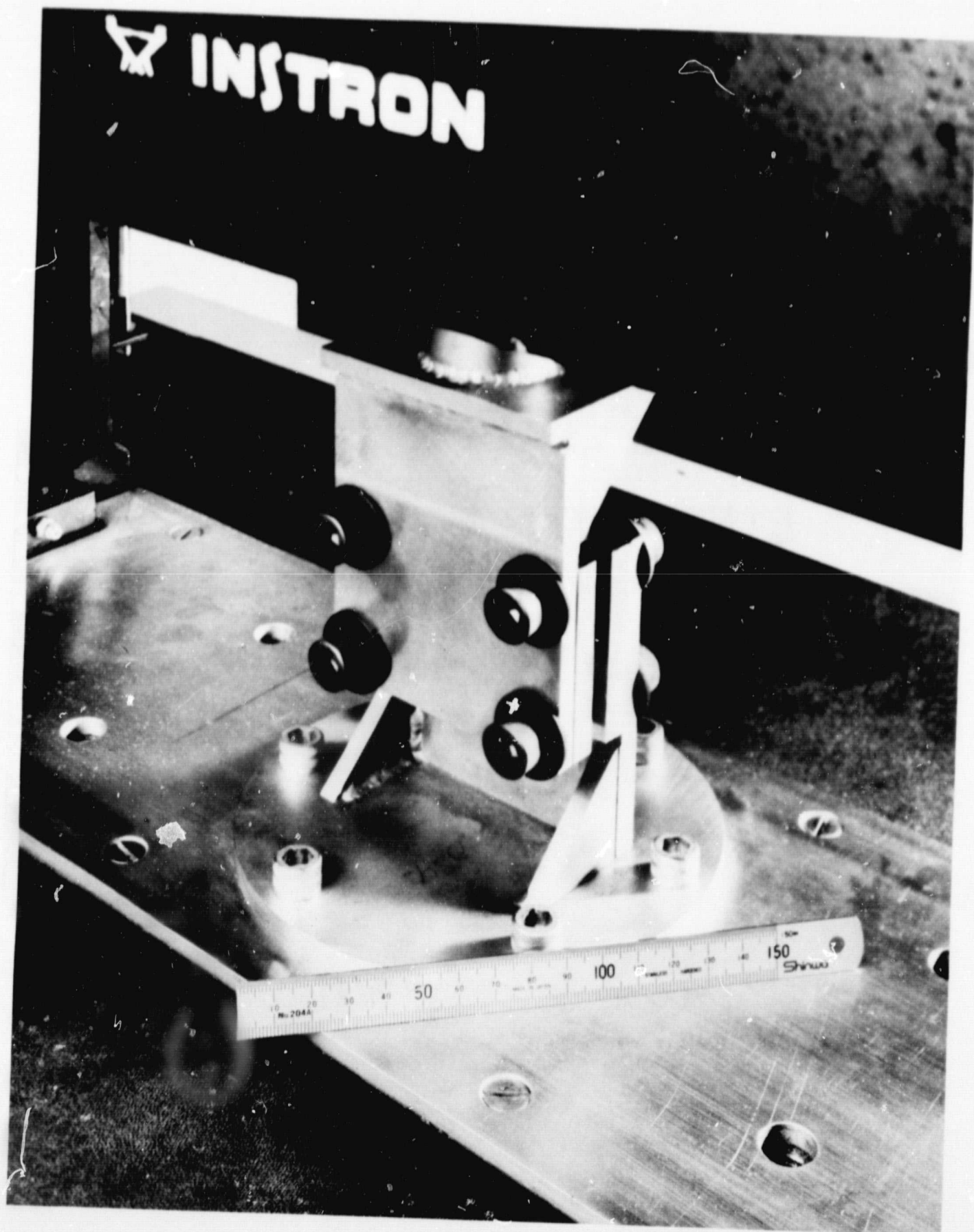
BELT 4 VENDOR B 05-14-80 RUNS 61-110 11S

Setting	nominal	
	No	HP
A	1.78	3200
B x	1.00	3200
C	1.00	1800
D	.56	1800
E o	1.78	3200
F	1.00	3200
G	1.00	1800
H	.56	1800



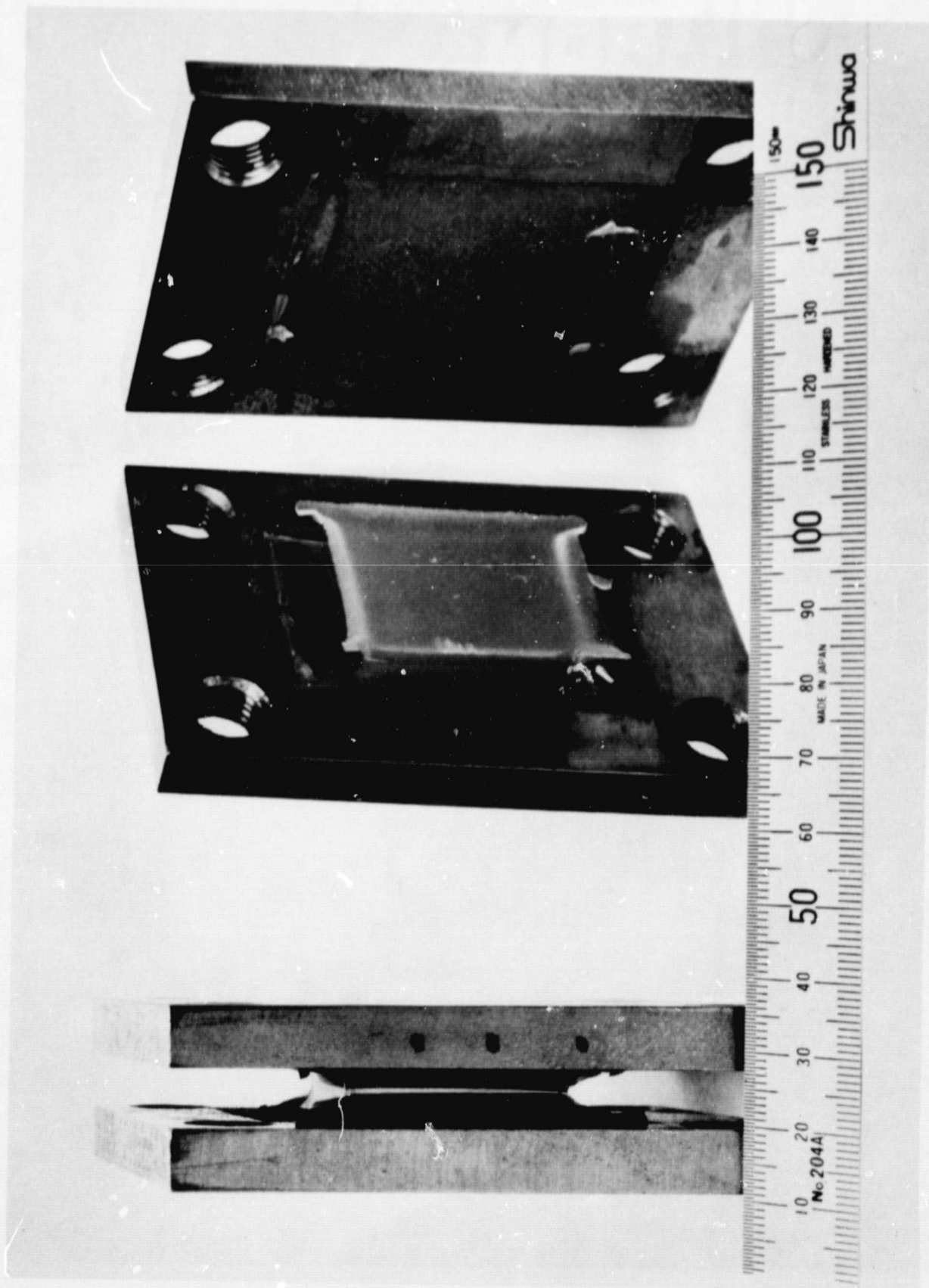
TRANSMISSION EFFICIENCY versus TRACTION RATIO
 LAMBDA, TR
 V-BELT TEST RIG
 UNCORRECTED DATA

FIGURE 23g



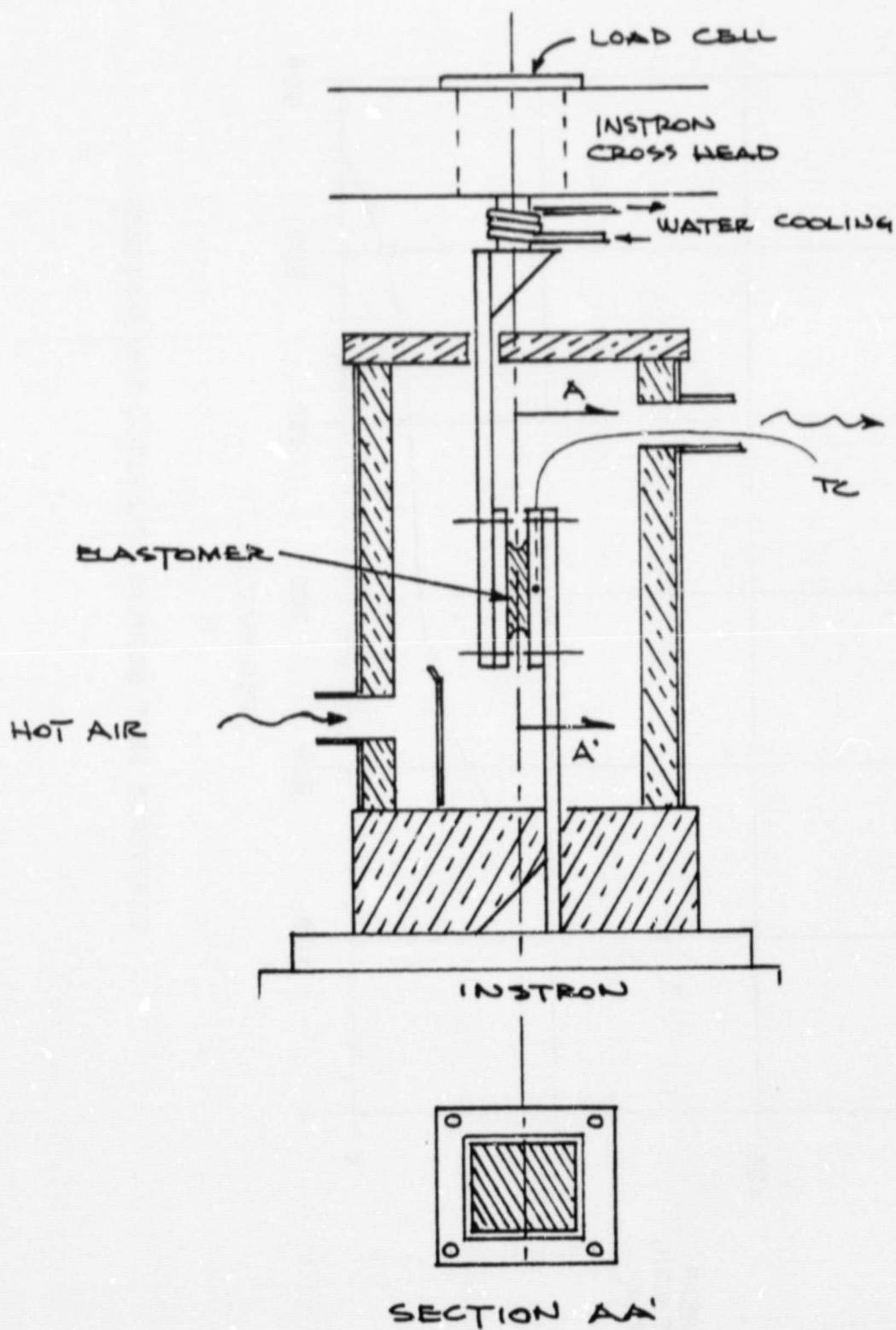
ELASTOMER SAMPLE SHEAR TEST FIXTURE

FIGURE 24



ELASTOMER SAMPLES BEFORE AND AFTER TEST

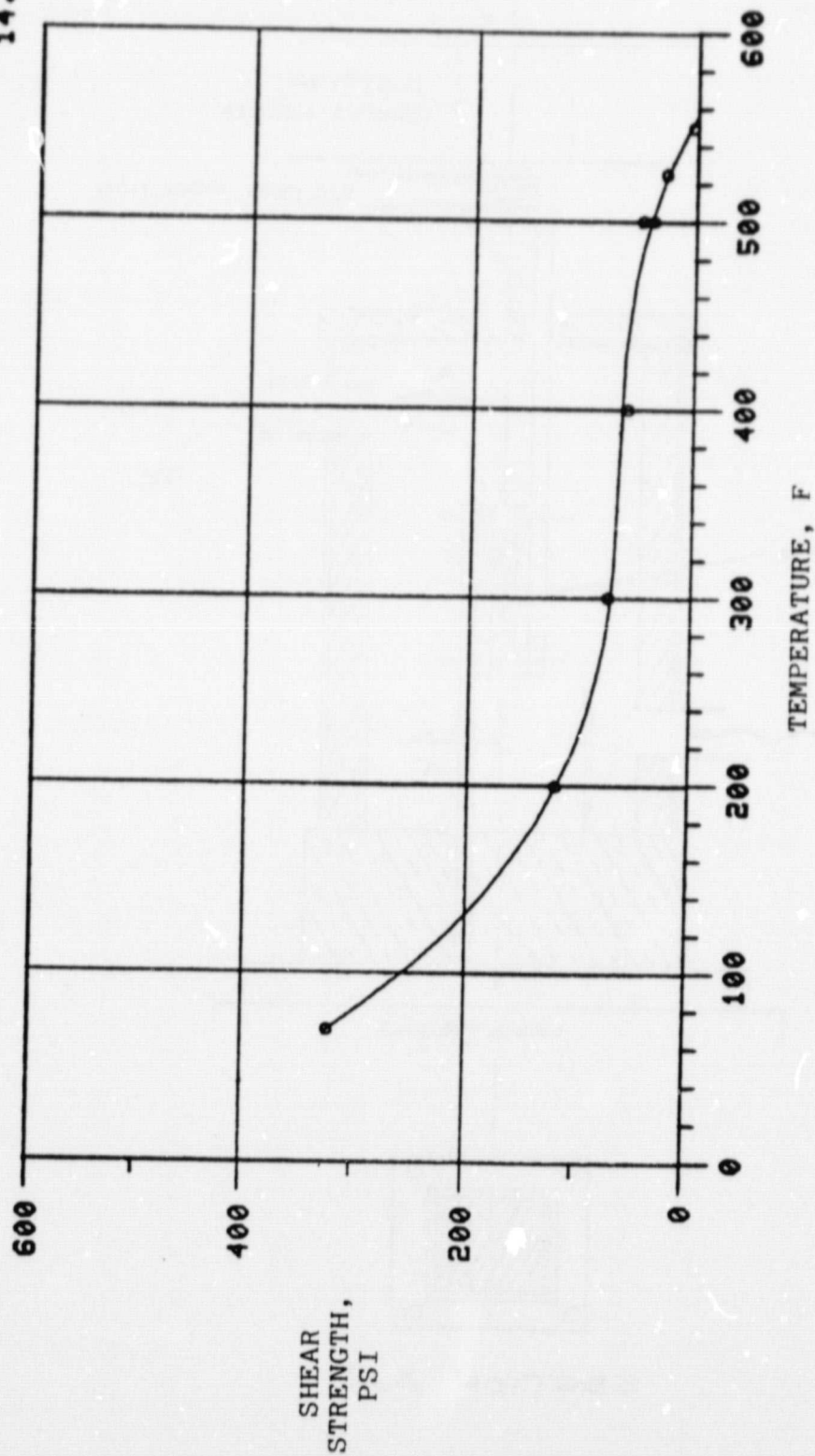
FIGURE 25



ELASTOMER SHEAR TEST FIXTURE
ELEVATED TEMPERATURES

FIGURE 26

03/09/81
14.44.39.



ELASTOMER TEST RESULTS, ELEVATED TEMPERATURES

FIGURE 27

A-926 CERAMIC REGENERATOR
PRESENT AND PROPOSED ELASTOMERIC MOUNTING SYSTEMS

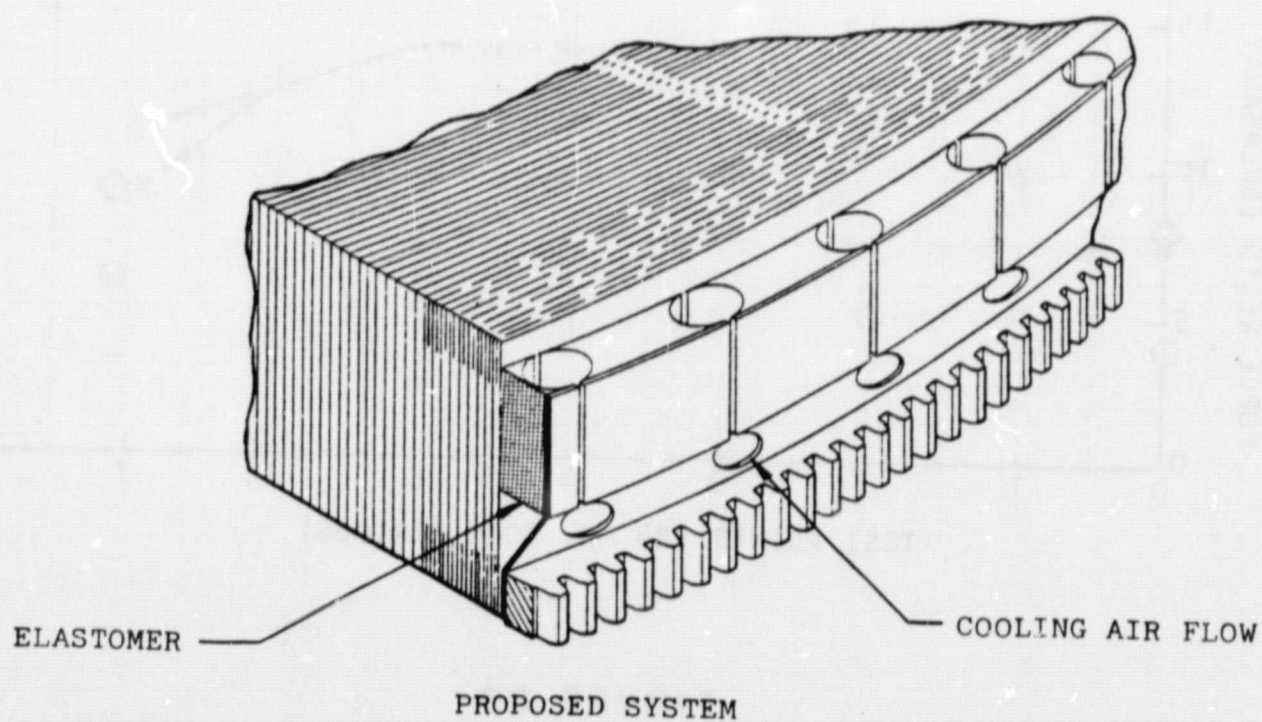
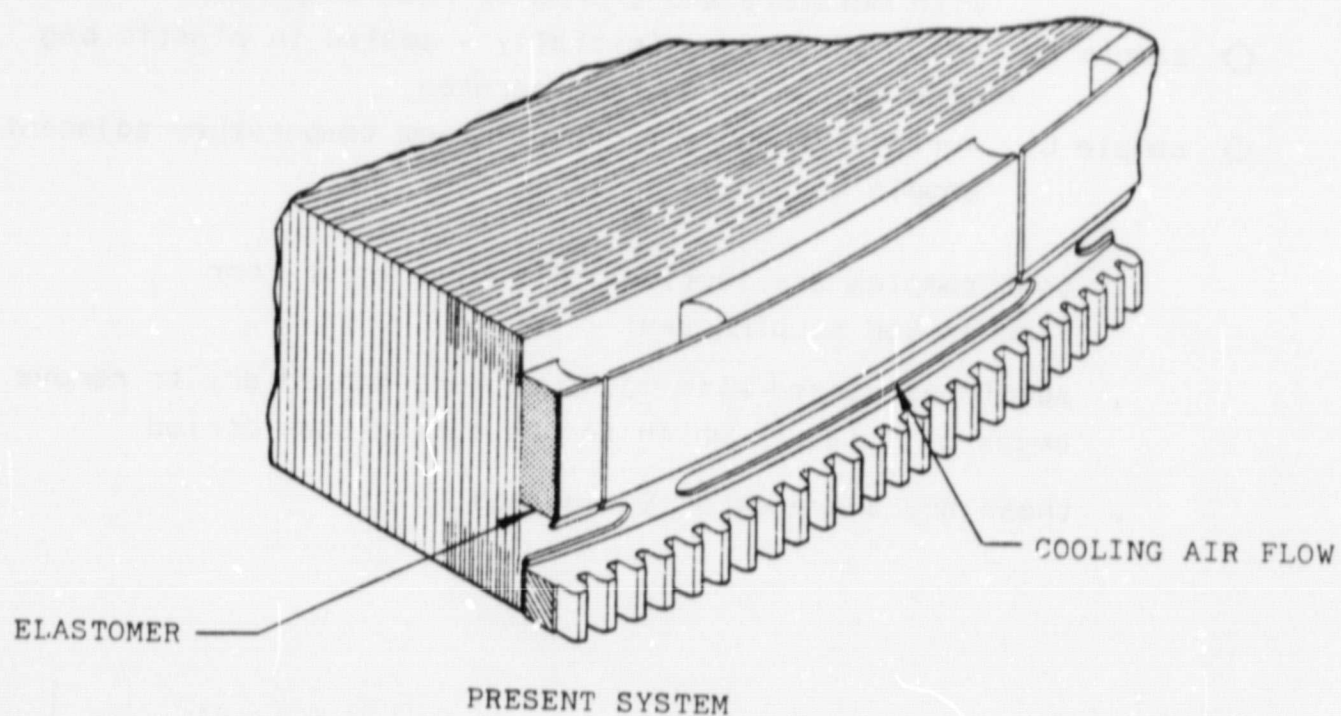


FIGURE 28

BREAKAWAY FORCE VERSUS TIME

HUMIDITY EFFECT ON GRAPHITE

- x sample A polished surface initially - sealed in plastic bag with moisture and stored at room temperature
- ◇ sample B polished surface initially - sealed in plastic bag with moisture and refrigerated
- sample C surface as-run - stored at room temperature adjacent sample A

- . test samples are sections of failed inner rear regenerator rubbing seal
- . specimens stored with moisture were dabbed dry to remove beads of moisture which formed during soak period
- . these are averages of 5 readings

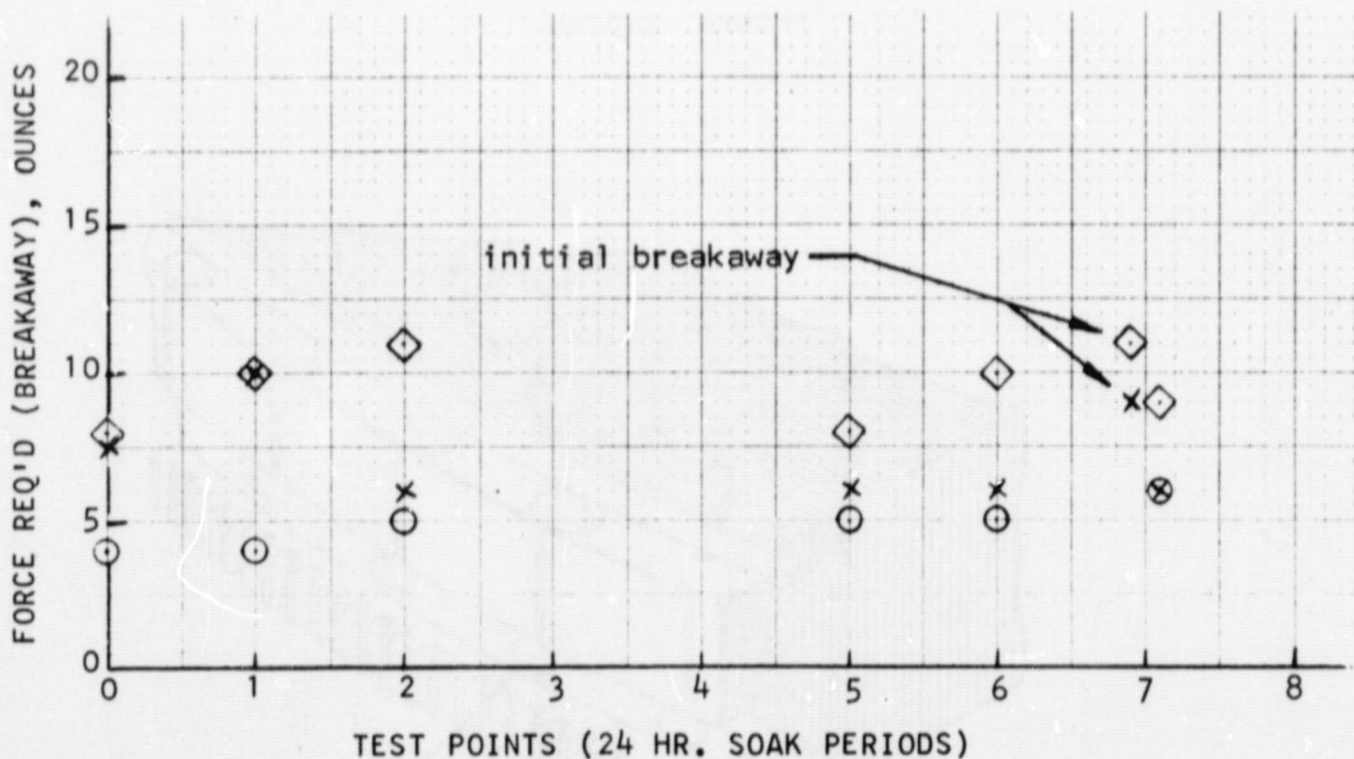


FIGURE 29

DELIVERY OF PARTS TO NASA LeRC

October, 1979 to February, 1981

02/03/81 Failed air bearings (6-2 and 21-1) and reports, shaft dynamics reports
01/14/81 CR 95 insulation, rear rotor seal, torch gasket and AN890 material
12/05/80 PTN actuator S/N 3, burner gaskets, misc. fittings
11/11/80 Air bearing S/N 25, middle seal, "O" rings
10/14/80 Final report Vol. 2
09/03/80 Outer regenerator seal, burner/torch gaskets, torch bolts
08/07/80 Burner cover S/N 3
08/18/80 Stainless allen screws, access panel screws, tab washers
07/31/80 CR 95 insulation, filler, Ludox
06/03/80 Final report Vol. 1, Vol. 3
05/28/80 Pre-mixer S/N 7, tube S/N 17, gaskets, burner parts
04/25/80 Engine, transmission, and misc. material removed from Car 649
04/17/80 Regenerator S/N 11, gaskets, fuel filter, air inlet foam gaskets
03/18/80 Final report Vol. 4, actuator S/N 4
03/03/80 Seal, rear inner-regenerator
02/13/80 Burner liner S/N 16
02/11/80 Base plates, graphite seal, regenerator, eccentric, Pro-Log
01/21/80 ECU, keyboard programmer, Pro-Log, fuel pump, fuel filter, misc. fuel system parts
01/14/80 Compressor turbine nozzle S/N 160
01/14/80 Assembly reduction gear S/N 4
01/10/80 Silicon carbide vortex, simulated rotor
01/09/80 Metering valve, PTN support, ring gear, PTN vanes, shrouds
12/21/79 Regenerator S/N 16, seals, torch bolts and washers
11/27/79 Oil pump S/N 55, oil pump pick-up
11/14/79 Large wall photographs of Car 386
11/01/79 Keyboard programmer, ECU
10/10/79 Assembly - PTN S/N 8 (less support)

P.R.	ITEM	P/N	QTY ORDERED	DATE ORDERED	DATE REC'D	ON HAND AS OF 2-28-81	UNIT COST	TOTAL COST	ACCU. TOTAL
B237A	6 CASTING - C.T.W.	4096391	4	1-7-80	5-17-80	4	395	1580	1580
B300A	6 PINION - P.T. (REPAIR)	4096322	1	1-4-80	2-22-80	1	400	400	1980
B301	6 BRG. - G.G. AIR FOIL	3815871	6	1-2-80	4-11-80	2	1000.	2000	3980
B302	6 KIT - ELASTOMER	4097219	2	1-14-80	1-28-80	PARTIAL	154	150	4130
B304	6 ADAPTER - BURNER TUBE	4096496	2	1-11-80	2-14-80	2	365	730	4860
B305A	6 P.T. ROTOR FINAL MACH.	3813807	2	1-14-80	7-14-80	1	1190	1190	6050
B306	9 SHEET PA 333	NN8306	1	1-18-80	4-1-80	PARTIAL	666	600	6650
B308A	6 SEAL - G.G. ROTOR - MIDDLE	3814525	25	3-7-80	NOT YET	0	246	6150	12800
B311	9 CORE - REGENERATOR (ROTOR)	3814227	2	1-24-80	3-25-80	2	425	850	13650
B312A	9 SEAL - REGEN. RUB / INNER RING	3814266	4	3-4-80	5-2-80	4	445	1780	15430
"	" " " FRONT	3814267	4	3-4-80	5-2-80	4	400	1600	17030
"	" OUTER SEAL - REGEN. RUB.	3814274	4	3-4-80	5-2-80	4	510	2040	19070
B313	9 FILTER - OIL	2805906	24	2-1-80	3-25-80	24	2.50	60	19130
B314	9 REFRACTORY CEMENT	NN8314	1 GAL.	2-4-80	2-7-80	PARTIAL	58	30	19160
B315	9 RING - RETAINER	3814446	250	2-5-80	2-25-80	234	.25	59	19219
B316	6 ENG. SERVICE - ULTRA	NN8316	2 DAY	3-11-80	3-14-80	0	849.	0	—
B317	7 SOL. VALVE - MAIN FUEL	SK-19781	6	4-1-80	7-21-80	0	28.50	0	—
B318	15 BORON CARBIDE	NN8318	10 LB	5-16-80	6-24-80	PARTIAL	208	1656	19384
B319	15 CARBON REMINERANT	NN8319	1	5-16-80	5-22-80	0	1800	0	—
B321	16 CABLE - PRINTER - ULTRA	SK-1001	2	7-3-80	10-2-80	2	150	300	19684
B323	17 SPRAY UNDERCOAT 3M	SK-1008	18	8-1-80	9-4-80	3	5	15	19699
B324	17 TOUCH UP SPRAY ORAL	4176189	24	8-7-80	8-15-80	0	3	0	—
"	" " " ADAPTOR	4176189	12	8-7-80	8-15-80	0	2	0	—
B325A	17 ACT. UPPER HOSE MHD	SK-1013	4	9-8-80	11-19-80	3	25	75	19774
"	" " " LOWER	SK-1014	4	9-8-80	11-19-80	3	25	75	19849

FIGURE 31a

APPENDIX A

Contract DEN3-144

UNITED STATES
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

SPECIFICATIONS
FOR SUPPORT SERVICES
FOR THE AUTOMOTIVE
GAS TURBINE PROJECT

SPECIFICATION 3-858476

I. GENERAL

The Government has supported development of automotive gas turbine engines and gas turbine-powered automobiles since 1972, principally through an EPA (then ERDA, now DOE) contract with the Chrysler Corporation (contract number EY-76-C-02-2749). The principal objective of this contract was the development of the Baseline engine vehicle, and the Upgraded engine and vehicles.

These vehicles have seen service in Washington, DC and have been displayed at various Government-sponsored conferences and meetings. Both Baseline and Upgraded engines and engine components have been provided to NASA-Lewis for use in-house research programs. In addition, Chrysler has prepared displays and exhibits for DOE's use in informing elements of the Government (Congress, OMB, etc.), industry, and the public about the DOE Heat Engine Program.

It is expected that the Government (both DOE and NASA-Lewis) will have a continuing need for the Baseline and Upgraded engines and vehicles, and for the various displays and exhibits previously prepared. Support services, maintenance, spare parts, etc. for the engines, vehicles and displays have been provided in the past by Chrysler as a task under the DOE contract. That contract will be completed on June 30, 1979. Therefore, this contract is required such that the same type of experience support continues to be provided for the engines and vehicles in the possession of the Government, and that the displays and exhibits are maintained and available by DOE's purposes.

II. SCOPE OF WORK

This Statement of Work describes the tasks to be performed by the Contractor to provide support to the Government, in the form of services and materials, to assist DOE in its efforts to inform the Government, industry, and the public of the DOE Gas Turbine Highway Vehicle Systems Program. This shall include repair, retrofit and maintenance of Baseline and Upgraded engines and vehicles used for demonstration or test purposes at Government facilities.

III. FUNCTIONS TO BE PERFORMED

A. Exhibits, Demonstrations, and Information

1. Task: Support the DOE Highway Vehicle Systems Office Gas Turbine Program in DOE's efforts to inform the Government, industry, and the public. To accomplish this, the Contractor shall prepare visual aids, exhibits, displays, and demonstrations of gas turbine vehicles and related information, equipment, or hardware for events involving the Government, industry, and the public as directed by the NASA Contracting Officer. The transportation, setup, and dismantling of displays shall also be provided. This support effort may require performing various tests to provide experimental data to demonstrate the performance potential of the automotive gas turbine engine.

2. Requirement: Personnel performing the services shall be qualified and knowledgeable automotive gas turbine specialists.

B. Maintenance, Repair, Retrofit, and Inspection

1. Task: Perform or provide for the routine and non-routine maintenance/repair/retrofit/inspection of the Baseline and Upgraded engines and vehicles as directed by the Contracting Officer to support the continuing operational needs of the Gas Turbine Project Office.

2. Requirement: Personnel performing the services shall be trained and qualified in the operation and maintenance of the Baseline and Upgraded engines and vehicles.

C. Materials and Spare Parts

Materials and spare parts needed for display purposes and for the maintenance/repair/retrofit/test/ of engines and vehicles as will be specified by the NASA Contracting Officer.

D. Reporting Requirements

The Contractor shall provide Monthly Financial and Technical Progress Reports in a format of his own choosing (corporate letterhead is acceptable).

1. The Monthly Financial Report shall provide for each Delivery Order the labor hours expended per category and the resources expended for the reporting period; an estimate of planned spending during the following month and the resources remaining in the contract.

2. The Monthly Technical Progress Report shall contain a narrative summary of the services performed under each Delivery Order, the problems encountered, hardware replaced and recommendations for future procedures and/or inspections to be performed, based on the Contractor's experience. Assessments of failures shall be reported. In addition, the Contractor shall document for each vehicle the hours, starts, and miles accumulated during the period and the cumulative totals.

3. The Contractor shall submit, by the fifteenth of the following month, six (6) copies of each required Monthly Report as directed by the NASA Contracting Officer.

4. A Summary Report describing the Contractor's experience in providing support and maintaining the engines and vehicles shall be prepared at the end of the contract period of performance. This report shall include all display and support services, the repair history, failure reports, utilization of spare parts, and suggestions for improvement.

5. The Contractor shall deliver twenty (20) copies of the Summary Report as directed by the NASA Contracting Officer within thirty days after the end of the contract period of performance.

APPENDIX B

NASA SERVICE CONTRACT DEN 3-144
DELIVERY ORDER SUMMARY, 1 THRU 21Page 1
1-29-81

D.O. NO.	TITLE	PURPOSE	DATE	AUTHORIZED		MATERIAL COSTS \$ 1000
				MAN	HR.	
1	Coordination Meeting Support.	Demonstrate Upgraded Gas Turbine Vehicles.	11-28-79	100		0.30
2	Reports of Work.	Monthly Reports.	11-28-79	—		3.00
3	V-Belt Testing.	Evaluate Variable Speed Rubber Belts from Dayco, Goodyear and Gates.	11-28-79	708.5		—
4	Turbine Car Demonstration, Daytona Beach, Florida.	Display and Demonstrate Upgraded Gas Turbine Vehicles for Members of IMSA and the General Public.	11-28-79	208		5.45
5	Turbine Car Demonstration, NASA Lewis Research Center.	Demonstration for Congressman Tom Harkin.	12-7-79	316		0.15
6	Retrofit/Repair of Engine 3 (PP2-3).	Retrofit/Repair and Update Engine PP-2-16. Procure Engine Parts.	1-9-80	988		13.20
7	Vehicle Maintenance.	Service Vehicles at DOE Headquarters, Washington, D.C., Ship Vehicles.	1-9-80	520		15.00
8	Control System Training Session.	Familiarize NASA Personnel with Engine Control System.	1-4-80	144		1.50
9	Maintain NASA Test Engines.	Provide for Repair, Services and Maintenance of the Upgraded Test Engines at Lewis Research Center.	1-4-80	1430		9.50
10	Engine Gas Generator Shaft Dynamics.	Document Shaft Dynamics over Operating and Starting Range.	1-25-80	1130		4.00
11	Provide Vehicle U-3 and Expanded Engine Display for NASA Exhibit, Cleveland, Ohio.	Display Upgraded Vehicle and Engine at the Home And Garden Show.	2-26-80	80		0.30

APPENDIX B

NASA SERVICE CONTRACT DEN 3-144
DELIVERY ORDER SUMMARY, 1 THRU 21

Page 2
1-29-81

NO.	TITLE	PURPOSE	DATE	AUTHORIZED MAN HR.	MATERIAL COSTS \$ 1000
12	Finalize Upgraded Engine Drawings and Parts List.	Correct, Update, Release Combustor, Regenerator, Power Turbine/Reduction Gear and Control Items.	3-80	650	—
13	NASA Exhibit, Cleveland, Ohio.	Display Upgraded Vehicle U-3 at the Sportsman Show.	3-17-80	60	0.30
14	Provide Vehicles U-2 and U-3 for 5th. Automotive Symposium; Hyatt Regency Hotel.	Demonstrate and Display Upgraded Gas Turbine Vehicles.	4-1-80	220	0.33
15	Repair, Service and Maintenance of Upgraded Gas Turbine Vehicles.	Maintain Upgraded Vehicles, Assemble Spare Engine Components, Procure Vehicle Components.	5-20-80	595	6.00
16	Repair, Service and Maintenance of Upgraded Gas Turbine Engines.	Complete Rotor Shaft Dynamics Tests. Regenerator Elastomer Investigation.	5-20-80	700	5.00
17	Update Vehicle, Dodge Aspen U-1 to Dodge Mirada U-4.	Purchase 1980 Vehicle, Modify.	7-2-80	1154	12.00
18	Complete Update of Vehicle U-4.	Complete Vehicle Update.	9-18-80	350	4.00
19	Display, Demonstrate Vehicles U-2 and U-3 in Washington, D.C. Display Vehicle U-3 in Daytona Beach, Florida.	Support to Congressman Tom Harkin and Members of Congress; Washington, D.C. Display Vehicle U-3 for Daytona Beach Community College National Conference For Automotive Educators.	9-26-80	200	9.50
20	Final Report.	Prepare Technical Summary.	9-30-80	—	4.00
21	Continue Servicing NASA Test Engines And Vehicles.	Maintain Test Engines at Lewis Research Center and Vehicles at Chrysler.	11-14-80	718	—

APPENDIX C

PART FAILURES AND DEFICIENCIES SUMMARY DEN 3-144

January, 1981
Page 1 of 2.

<u>F.R. No.</u>	<u>Item</u>	<u>Part No.</u>	<u>Description of Failure, Deficiency</u>	<u>Corrective Action, Recommendation</u>
74	Power Turbine/Red. Gear Assy. 3		Pinion Journal & Thrust Brgs.	The reduction gear bearing system was updated.
75	Over Running Clutch Assy.	3814425	Plastic Sprag Retainer separated from clutch assy	Replaced clutch assy.
76	Assy.-Accessory Drive Electric	3814489	Weld failure	Improve fabrication
77	Bolt-Push Rod to Ring Gear Lever	3814223	Bolt sheared at shoulder	Canvas existing supply, replace as req'd.
78	Assy, Regenerator Core	3814226	Elastomer Pads sheared	Upgrade elastomer mat'l. in process on AGT
79	Boot-Air Intake	3814394	Material torn	Improve intake to boot adaptor
80	Vehicle-complete	U-3	Body & Vehicle accessory damage. Due to method of transport	Reinforce frame hold downs, improve vehicle tie-down technique
81	Assy, Regenerator Core	3814226	Elastomer Pads sheared	Upgrade elastomer mat'l. in process on AGT
82	Electronic Control Unit	3814456	Loss of counts, signal conditioning	Modify board 6 of ECU. See letter H. P. LeFevre to J. Gross 3-21-80
83	Assy, Regenerator Core	3814226	Elastomer Pad sheared	Upgrade elastomer mat'l. in process on AGT
84	Wheel Compressor Turbine	4096402	"Indications" at the blade root fillet	New castings are OK
85	Engine Housing-Complete	3814204	Instability of the Hsg. bulkhead, loss of P.T.-interstage pilots	Investigate cause of loss of pilot w/baffled hsg. Set PTW cl. at .014 in.min.
86	Vehicle-complete	U-2	Body & Vehicle Accessory damage	Reinforce frame hold downs, improve vehicle tie-down technique

APPENDIX C

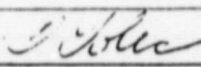
January, 1981
page 2 of 2.

PART FAILURES AND DEFICIENCIES SUMMARY DEN 3-144

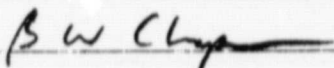
<u>F.R. No.</u>	<u>Item</u>	<u>Part No.</u>	<u>Description of Failure, Deficiency</u>	<u>Corrective Action, Recommendation</u>
87	Electronic Control Unit	3814546	Loss of light off Sensing & Cranking Timer Safeties	Return to vendor
88	Electo-Magnetic Clutch	U-3	Power Lead to Clutch Shorted	Problem attributed to transport of vehicle
89	Vehicle Complete	U-3	Body & Vehicle Accessory damage	Continue to improve vehicle transport technique
90	Power Turbine Nozzle Actuator	4C96650	Shaft/Bore Galled	Alum. hsg. was not anodized. Part was rebored and anodized
91	Air Bearing-Gas Gen. Rotor	3813371 S/N 6-2	Fracture of smooth foil thru spot weld area	Redesign method of foil attachment
92	Air Bearing-Gas Gen. Rotor	3813371 S/N 21-1	Fracture of smooth foil thru spot weld area	Redesign method of foil attachment
93	Vehicle Complete	U-2	Engine cycles after a cold start resulting in smoke, odor	Replace leaded gasoline/diesel mixture with commercial grade of unleaded fuel.

CAR NO. NASA-LEWIS RES. C.	MODEL A-926	DATE 9/8/79	ODOMETER	SERIAL NO. PP 2-3BO
PART FAILURES AND DEFICIENCIES 9520-926-74				
ISSUED TO: DEPT. NO. 9010 MR. C.E. Wagner				
PART NAME: Power Turbine/Reduction Gear Assembly 3				
PART NUMBER:				
MILES ON PART: 108.5 hours, Pinion Journal 8, 258.4 hours, PTW 202				
TYPE OF OPERATION: Transient Tests, Emission Test at NASA LeRC, Cleveland, OH				
BODY STYLE:				
DESCRIPTION OF FAILURE OR DEFICIENCY: The engine was returned from NASA to the Research lab for retrofitting. (Mod 3 gas generator and Mod 2 power turbine) There was no report of engine failure, although control of engine speed was erratic. Partial disassembly revealed the following damage:				
1. The regenerator core 12 (341.1 hours) was glazed for a 60° sector due to over temperature. The unit can be salvaged. The inner, rear regenerator seal was cracked.				
2. The power turbine thrust bearing was failed. The sleeve bearing moved forward axially in the aluminum support but was not seized on the pinion journal. The journal is barrel shaped and crazed. Discoloration of the bearing assembly is minimal, indicating presence of oil cooling. The pinion/journal can be salvaged by metal spraying and grinding.				
3. The power turbine wheel moved forward gently contacting the interstage assembly. The wheel is salvageable.				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 870, PROVING GROUND)				
FORM 128-6731				
CHRYSLER CORPORATION ENGINEERING STAFF				
ROYAL MCBECK - DETROIT				

CAT NO	MODEL	DATE	ODOMETER	SERIAL NO.
NASA LeRC	A-926	9/8/79		PP 2-3BO
PART FAILURES AND DEFICIENCIES				
ISSUED TO: DEPT. NO. 9010 MR. C.E. Wagner				
PART NAME: Power Turbine/Reduction Gear Assembly 3				
PART NUMBER:				
MILES ON PART				
TYPE OF OPERATION:				
BODY STYLE:				
DESCRIPTION OF FAILURE OR DEFICIENCY:				
4. The intake system and compressor discharge ducting is severely contaminated with a sooty substance noted in all gas generators returned from the NASA facility. The engine will be retrofitted as planned.				
lg				
cc: P.R. Angell P. Kerwin (NASA)				
G.A. Ball R. Padovini				
A. Billington R.F. Pauley				
J.H. Engel R.S. Rarey				
T. Golec N.W. Sparks				
J.V. Gross E.Z. Trieskey				
F.A. Hagen				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 870, PROVING GROUND)				
FORM 228-1/75				
CHRYSLER CORPORATION ENGINEERING STAFF				
ROYAL MCBE - DETROIT				

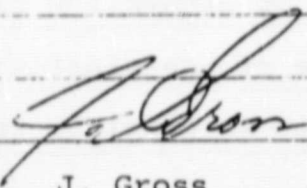
TRUCK NO. NASA LEWIS RES. CENTER	MODEL A-926	DATE 9/20/79	ODOMETER ---	SERIAL NO. PP9-11 G
PART FAILURES AND DEFICIENCIES 9520-926-75				
ISSUED TO: DEPT. NO. 9010 MR. C. E. Wagner				
PART NAME Overrunning Clutch Assembly				
PART NUMBER 3814425 (Not Serialized)				
MILES ON PART -- Refr: Failure Reports 9520-926-18 & 64				
TYPE OF OPERATION Transient Tests, Emission Tests at NASA Lewis Res. Center Cleveland, OH				
BODY STYLE				
DESCRIPTION OF FAILURE OR DEFICIENCY Overrunning clutch components, (Springs & Sprags), were found in the oil pan. The cause and time of failure is unknown, engine operation was unaffected by the failure. Examination of the clutch indicated that the front plastic sprag retainer had separated from the clutch assembly allowing the sprags and springs to fall out.				
 10/18/79 Tom Golec				
cc: A. Billington				
T. Golec				
J. Gross				
F. Hagen				
P. Kerwin (NASA)				
E. Kohl				
R. Padovini				
N. Sparks				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO. 386	MODEL DODGE ASPEN	DATE 10/23/79	ODOMETER 5470.6 MI. 375.3 HR	SERIAL NO PP10-14AF
PART FAILURES AND DEFICIENCIES 9520-926-76				
ISSUED TO: DEPT. NO. 9010 MR. C. E. Wagner				
PART NAME Ass'y - Accessory Drive Electric				
PART NUMBER 3814489				
MILLS ON PART				
TYPE OF OPERATION Ride/Drive Demonstration				
BODY STYLE				
DESCRIPTION OF FAILURE OR DEFICIENCY Low oil pressure was observed during the start cycle. When the power turbine/reduction gear accelerated to idle speed, pressure was normal indicating a malfunction in the starter gear box/electric clutch drive system. The key, P/N 3814582, welded to insert 3814583 of electric clutch ass'y 3814589 failed at the weld. The hex drive shaft disengaged. The clutch assembly was replaced. The failed unit can be salvaged.				
<div style="text-align: right;"> <i>Tom Golec</i> 10/30/79 Tom Golec </div>				
cc: A. Billington				
T. Golec				
J. Gross				
F. Hagen				
Paul Kerwin (NASA) R. Padovini				
E. Kohl N. Sparks				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO.	MODEL	DATE	ODOMETER	SERIAL NO.
386 (U-2)	A-926	1/04/80	5610	PP 10-14AG
PART FAILURES AND DEFICIENCIES 9520-926-77				
ISSUED TO: DEPT. NO. MR.				
PART NAME BOLT-PUSH ROD TO RING GEAR LEVER				
PART NUMBER 3814223 NOT SERIALIZED				
MILES ON PART PROBABLY 168 HOURS, 2200 MILES (running time for PP 10-14 in car)				
TYPE OF OPERATION: VEHICLE				
BODY STYLE Material 410 SS; hardness spec 39RC; torque spec 35 lb in.				
DESCRIPTION OF FAILURE OR DEFICIENCY				
Shoulder bolt separated at bearing surface while reinstalling power turbine nozzle actuator. Bolt was found to have previous crack extending 30% of section. Hardness checked 33 RC at head, 25 RC at shank. This may be due to operating and soak back temperatures exceeding that for 39 RC tempering (315° C). Material or design changes are being considered.				
 Bruce Chapman				
cc: A. Billington				
T. Golec				
J. Gross				
F. Hagen				
Paul Kerwin (NASA)				
E. Kohl				
R. Padovini				
N. Sparks				
/mtt				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735 CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO. NASA- Lewis Research Center	MODEL A-926-1	DATE 12/19/79	ODOMETER 152.4 Hrs.	SERIAL NO. PP 9-11I
PART FAILURES AND DEFICIENCIES 9520-926-78				
ISSUED TO: DEPT. NO. 9010 MR. C.E. Wagner				
PART NAME ASSEMBLY - REGENERATOR CORE, COMPLETE				
PART NUMBER 3814226 S/N 7				
MILES ON PART 152.4 Hrs.				
TYPE OF OPERATION: TRANSIENT AND STEADY-STATE PERFORMANCE TESTING AT NASA				
BODY STYLE N/A				
DESCRIPTION OF FAILURE OR DEFICIENCY: The elastomeric pads of the regenerator drive system failed while running under 90% Ngg steady-state conditions at NASA. The engine reportedly ran for several minutes after the core stopped turning, as evidenced by a heavy rub between the rim and cover. The majority of pads appeared to have sheared circumferentially at the mid-point, with a few pads showing small areas of secondary matrix breakage. There was no evidence of adhesive failure at either the rim or matrix surfaces. This is the first failure of the elastomer pads in shear since the A-926 program began. It is possibly related to the conversion to Sylgard 186 Elastomer, since Dow Corning has discontinued manufacture of the previously used Sylgard 187. All parts are salvageable. It is recommended that NASA install exhaust gas (T ₉) overtemperature safeties for future engine tests.				
A. Billington 1/7/80				
cc: T. Golec/J. Gross/F. Hagen/Paul Kerwin (NASA)/E. Kohl R. Padovini/N. Sparks/R. Warren				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

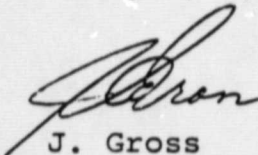
INFORMATIONAL

XXXXXX 649 U-3	MODEL A-926 Gas Turbine	DATE 1-29-80	ODOMETER 279	SERIAL NO PP8-10L
PART FAILURES AND DEFICIENCIES A-926-9520-79				
ISSUED TO: DEPT. NO. 9010 MR. C. W. Wagner				
PART NAME Boot - Air Intake				
PART NUMBER 3814334				
MILES ON PART: 279 Miles				
TYPE OF OPERATION: Vehicle Demonstration/Display				
BODY STYLE				
DESCRIPTION OF FAILURE OR DEFICIENCY: The boot was cut at the two front corners; as a result the filter system was by-passed. The aluminum intake duct was also damaged due to relative movement between the duct and engine proper. This damage is attributed to the excessive amount of shipping this vehicle has been subjected to. It is estimated the vehicle has been shipped in excess of 8200 miles on North American highways plus a 6000 mile round trip to Essex, England.				
 J. Gross				
cc: P. R. Angell G. A. Ball J. H. Engel T. Golec J. V. Gross (3) R. Padovini R. S. Rarey E. Z. Trieskey *P. Kerwin (NASA) R. F. Pauley				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO. Car 649 D-3	MODEL A-926 Gas Turbine	DATE 2/21/80	ODOMETER 307	SERIAL NO. PP8-10L
PART FAILURES AND DEFICIENCIES			9520-926-80	
ISSUED TO: DEPT. NO. 9010 MR. C. E. Wagner				
PART NAME: Vehicle Complete (PIC)				
PART NUMBER:				
MILES ON PART: 307 Miles				
TYPE OF OPERATION: Vehicle Demonstration/Display - Daytona Beach, Florida				
February, 1980				
BODY STYLE: Special Modified 1977 LeBaron Coupe				
DESCRIPTION OF FAILURE OR DEFICIENCY: The vehicle returned from a D.O.E. sponsored display at Daytona, Florida. Total shipping distance in North America has increased to 10,200 (total distance shipped in world is now 16,200 miles).				
The vehicle sustained additional damage during this last trip and is itemized below.				
1. Right stub frame rail cracked on outboard, underside and inboard sides. Fracture is aft tie down hole and is attributed to tie down shipping technique. The left side does not show failure yet. As a result the radiator yoke is forward on the right side.				
2. Oil cooler fan failed two of three mounts and was hanging down. Unit is still operational.				
3. Oil cooler failed two upper mounts. In addition the two cooler flanges are almost totally failed. Cooler somewhat supported by oil lines.				
CINS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

4. Excessively large uneven gap between right door and front fender. This is attributed to the failed and distorted stub frame/radiator yoke (Item No. 1). The fender line is also outboard the door .06/.12 inch.
5. The A/C condenser outlet tube is cracked at the tube support. In addition, fin damage occurred when the oil cooler support bracket chafed the condenser due to the failed cooler flanges as the support was free to pivot about the lower isolation mounts.
6. Lower screw on starter gear box loose. Backed out approximately two turns.
7. Exhaust pipe cracked at mid span and is four-five inches long. Also local heavy indentations from hitting van system during loading and unloading.
8. Rear section of lower control arm appears to indicate additional chafing due to possible tie down routing along this member.
9. Air spoiler sustained additional damage to bottom and corner. Appears that tie down routing and/or vehicle transported attitude is cause.
10. Sill bead heavily damaged beneath and toward rear of right door. Same fore and aft area as exhaust pipe damage.
11. Floor pan of vehicle shows additional abrasion at random areas.
12. Left fender rocker panel trim loose.
13. Tie down brackets at rear of vehicle are bent inward. Right side is considerably more than the left.

14. Rear shackles both sides lean inboard. Shackles brackets may be bent.
15. Rear stone shield shows additional damage from tie down hardware.
16. A/C line at receiver dryer outlet fell off.
17. Failed hook on battery hold down, battery loose to bounce around.
18. The new filter box boot installed has been cut by the filter box. The filter box outlet flange was again heavily damaged. The flange was reworked and new boot replaced 6.1 Hr, 2000 miles previously (Reference: Failure Report A-926-9520-79). This will require a major effort to provide required shipping clearance.
19. Two of four bolts holding ECU to tray are loose.
20. The fiberglass filler covering hood steel ribs is cracking and delaminating.
21. The hood/engine housing abrasion continues.
22. The fiberglass skins continued to develop additional spider cracks, in addition the existing cracks appear to be progressing.
23. The hood air cylinders no longer assist upon unlatching.
24. The sheet metal cracks at firewall/fender continue to grow.
25. Reference Photos: 9080-41 - 1, 2, 3, 4 and 5.


J. Gross

JG/bjc

cc: P. R. Angell, G. A. Ball, J. Corwin, F. Hagen, T. Golec, J. Gross (3)
R. Padovini, R. S. Rarey, E. Z. Trieskey, P. Kerwin, R. F. Pauley
B. Chapman, G. F. Stecher (2)

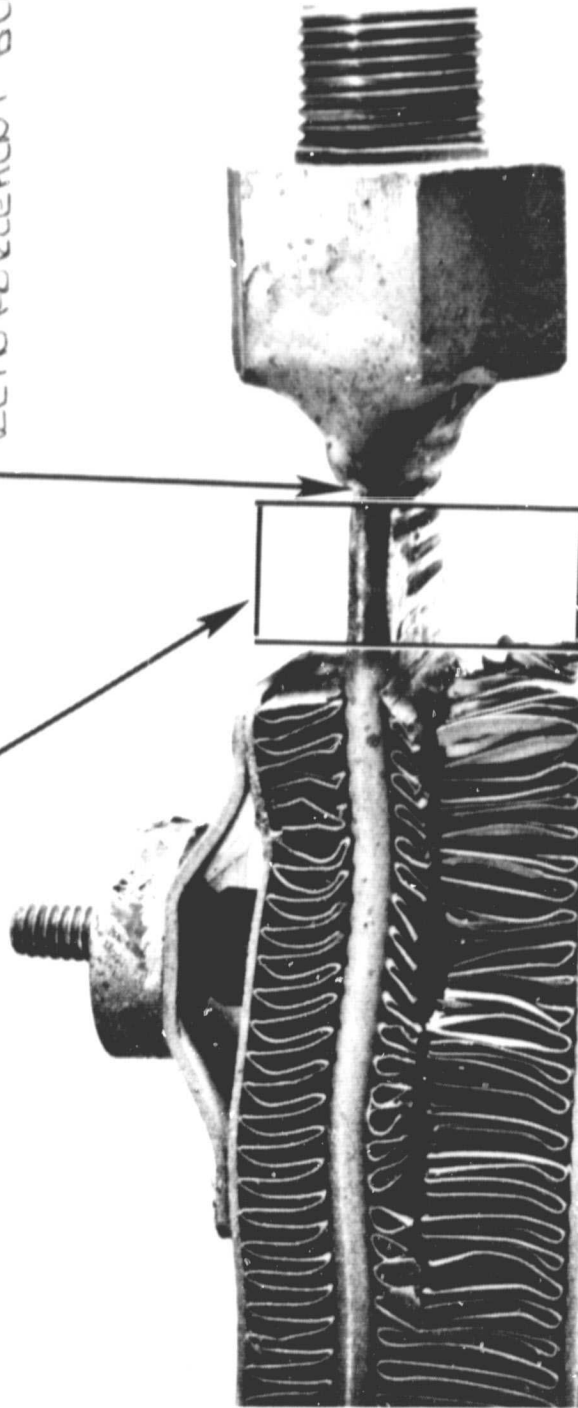
CAR 649 PP 8-10L
307.0 MILLS DRIVEN
16,200 MILLS SHIPPED (EST.)
OIL COOLER FAN



DAMAGED/SWAGED
ISOLATION MOUNTS

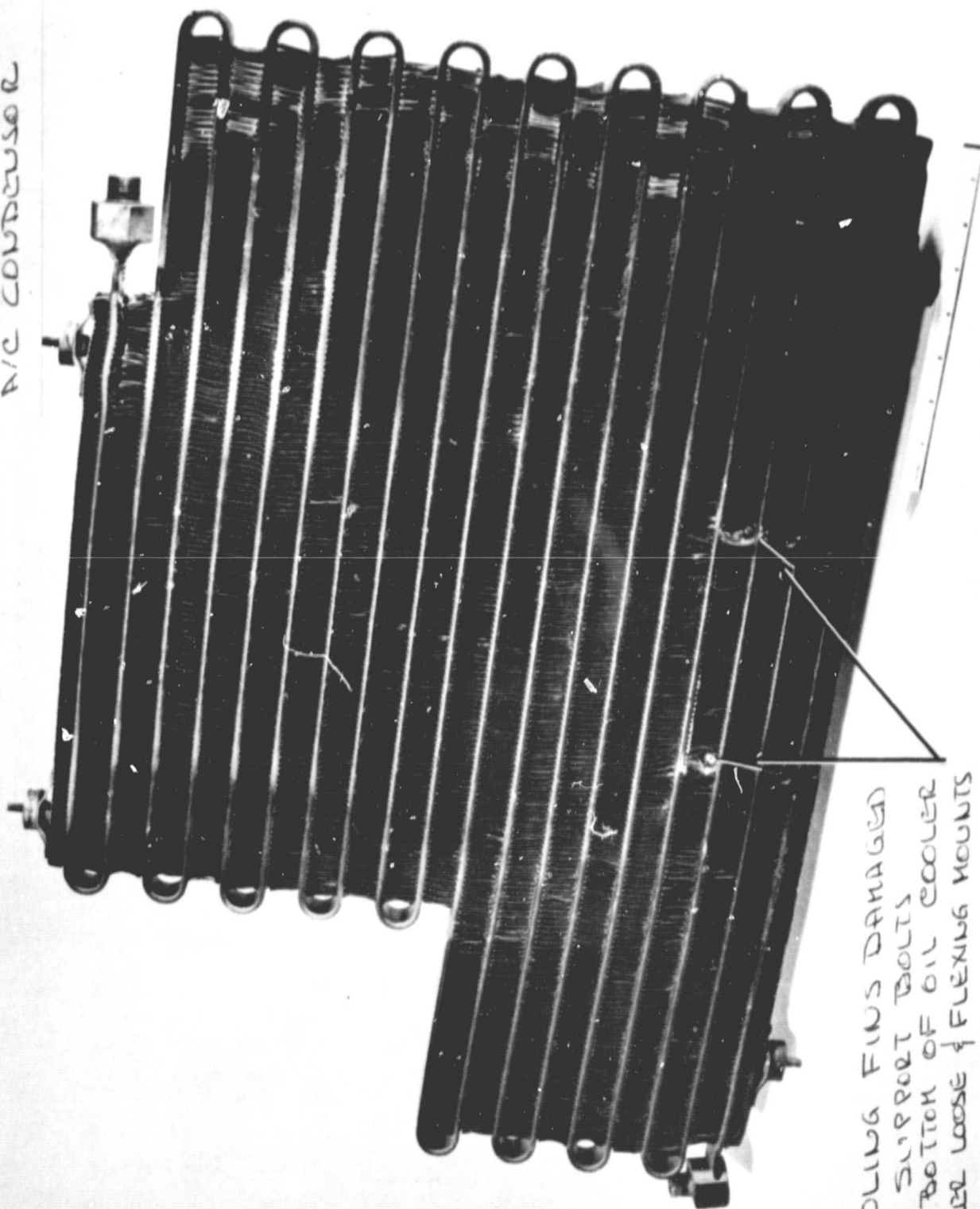
A REINFORCEMENT BLOCK
NORMALLY OCCUPIES THIS
AREA.

TUBE CRACKS ON UPPER
SURFACE (NOT VISIBLE IN
THIS VIEW) AND ADJACENT
REINFORCEMENT BLOCK



CAR 645 PP 8-10L
307.0 MILES DRAWN
16,200 MILES SWIPPED (EST.)
A/C CONDENSER

CAR 649 PRB-10L
307.0 HOURS DRIVEN
16,200 MILES SHIPPED (EST)
A/C CONDENSER



COOLING FINS DAMAGED
BY SUPPORT BOLTS
ON BOTTOM OF OIL COOLER
COOLER LOOSE & FLEXING MOUNTS

CAR 64'S RP 8-10L
3070 MILES DRIVEN
16,200 MILES SHIPPING (EST.)
OIL COOLER & LOWER SUPPORT

COOLER FLANGE EXHIBITS
CONSIDERABLE CRACKING
IN AREAS ACCENTUATED

CAR 643 PP8-10L
3070 MILES DRIVEN
16,200 MILES SHIPPED (EST.)
OIL COOLER UPPER FLANGE

UTL FLANGE FAILURE.
NATURAL FATIGUED AND
BRAKE OUT. ASSOCIATED
PIPPES FASTENED TO SCRAMB

TRUCK NO. NASA-LEWIS RESEARCH CEN.	MODEL A-926-1	DATE 2-5-80	ODOMETER N/A	SERIAL NO. PP 9-11 J
PART FAILURES AND DEFICIENCIES 9520-926-81				
ISSUED TO: DEPT. NO. 9010 MR. C. E. Wagner				
PART NAME Assembly - Regenerator Core, complete				
PART NUMBER 3814226 S/N 16				
MILES ON PART: 128.7 Hours on Regenerator; 8.2 Hours on Elastomer				
TYPE OF OPERATION: Steady-state and transient dynamometer testing at NASA, Cell CE-28.				
BODY STYLE N/A				
DESCRIPTION OF FAILURE OR DEFICIENCY: Prior to the failure, the engine had been running at 100% mechanical speed (58,500 rpm actual) with a 49°F inlet. Corrected speed was 103.5% of design. Gradually increasing P8 fluctuations were noted, and the speed was reduced to 90%, but the fluctuations worsened, accompanied by T5 and T8 spikes. Engine speed and torque then began to decay, and the engine was shut down.				
On disassembly, seven of the ten elastomer pads were found sheared. A large section of matrix material between two pads was missing, apparently not related to the failure of the adjacent elastomer. The graphite seals were heavily and unevenly worn, indicating the passage of a coarse abrasive material between the regenerator rim and the seals. The inner rear rim seal had white deposits in the pressure balancing grooves, and both it and the outer "D" seal were broken. The broken outer seal was caused by the unrestrained rim striking one of the retaining tabs on the baseplate. The cold face of the matrix showed several "prints" of				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-5735				
CHRYSLER CORPORATION P. P. & D. STAFF				

the crossarm area of the graphite "D" seal. See photos 9080-42, 43, and 44.

A review of regenerator S/N 16's test history showed that the core had accumulated 120.5 hours prior to failure in Car 386 (PP 10-14 0) on September 23, 1978. As noted in Failure Report No. 64, a control problem had allowed the regenerator area to become saturated with unburned gasoline, causing rapid swelling and deterioration of the elastomer. The regenerator was then baked at 1000°F to volatilize all traces of organics, and repotted. Unfortunately, at that time (November, 1978) there was some question as to the quality of the Sylgard 186 elastomer then on hand, and so it was decided to use an older stock of Sylgard 187 material, which appeared to have better mixing and curing properties than the 186. This material had been received June, 1976, and thus at the time of potting had an age of 29 months, as compared to Dow Corning's guaranteed shelf life of six months.

From the above, it is possible that the elastomer failure resulted from the use of material which had aged far beyond its intended shelf life, with resultant loss of mechanical properties. Samples of the failed elastomer will be analyzed in an attempt to verify this. Another cause or contributing factor may have been excessive torque loads resulting from:

1. Contamination of the seal rubbing surfaces with broken matrix material, presumably caused by handling damage, and/or
2. Excessive clamping forces during extended overspeed operation. A 103.5% test condition will increase P_2 , and therefore, drive torque, by up to 10%.

Two other test conditions may also have contributed to the failure. First, the photo-like seal images on the matrix cold face suggest a transfer of graphite into the ceramic under static and/or start-up conditions. It is believed that this adhesive bonding between the graphite and matrix occurs under high moisture conditions, since the coefficient of friction of graphite is quite high when damp. Based on previous observation of heavy deposits of combustion products in the compressors of engines run in CE-28, it is known that a strong back-draft exists in the cell exhaust stack between engine tests. This back-draft exposes the graphite seals to high humidity from combustion and atmospheric moisture, especially when development work requires frequent restarts (the 8.2 hour build before the failure had 27 starts). The problem is aggravated by the hygroscopic nature of the phosphoric acid impregnation used to give the graphite (speer carbon Grade 7110) its high-temperature properties. Until the heat of operation dries the graphite surface, this dampness can cause excessive torque load on the elastomer.

The second condition may have been exposure of the elastomer to unburned gasoline vapors during the numerous false starts reported in CE-28. The fuel supply system in this facility does not duplicate the vehicle system for which the burner was designed, allowing aerated return fuel to be recirculated into the burner, leading to burner instability and flame-out. While the exact relationship between exposure to gasoline vapors and deterioration of elastomer properties is unknown, the earlier failure in Car 386 suggests that such conditions should be avoided or minimized.

To prevent recurrence of elastomer failures of this nature, the following steps will be taken at Chrysler:

1. All cores with suspect elastomer will be repotted with new material now on hand, and elastomer and primer stocks will be replaced every six months.
2. When each core is potted, shear test samples will be prepared and cured at the same time, and then tested to failure to verify material integrity.
3. A Chrysler Research Procedure (CRP) will be issued to define and standardize the correct potting method.
4. Corning Glass Works has been requested to supply an updated procedure for repair of the refractory cement coating on the Matrix O.D. This information will also be issued in the form of a CRP.

It is also recommended that NASA consider the following:

1. Regenerators should be carefully handled at all times, and thoroughly inspected just prior to installation to verify the integrity of the matrix and protective cement on the rims and O.D.
2. Testing should be limited to speeds, temperatures, and pressures within the engine's published design envelope, and operating time at any maximum design condition should be minimized.
3. The exhaust stack in CE-28 should be fitted with a positive acting exhaust damper, to prevent back-drafting of moisture and other combustion products into the engine.

4. CE-28 should be equipped with a float bowl in its fuel system, simulating the vehicle's fuel tank, to prevent recirculation of air to the fuel metering valve and thus reduce false starts and flame-outs.

A. Billington

A. Billington
3/6/80

AB/bjc

cc: P. R. Angell
G. A. Ball
J. Corwin
F. Hagen
J. V. Gross (3)
R. Padovini
R. S. Rarey
E. Z. Trieskey
P. Kerwin (NASA)
R. F. Pauley

TRUCK NO.	MODEL	DATE	ODOMETER	SERIAL NO.
Room 125	A-926-1	3/25/80	--	PP2-16C
PART FAILURES AND DEFICIENCIES 9520-926-82				
ISSUED TO: DEPT. NO. 9010 MR. C. E. Wagner				
PART NAME: Electronic Control Unit				
PART NUMBER 3814546 SN3 (Ultra C4E86/4 SN111), PCB6 SN111; > 400 Hours				
and SN5 (Ultra SN113), PCB6 SN113; > 150 Hours				
TYPE OF OPERATION: Test cell; first operation of 18-18 blade impeller with				
18 blade steel inducer.				
BODY STYLE				
DESCRIPTION OF FAILURE OR DEFICIENCY: No throttle control above 85 percent Ngg with				
either ECU or gas generator speed pick-up. This was caused by				
"loss of counts" by the signal conditioning circuit on Board 6.				
Speed control to 100 percent Ngg was attained by modifying this				
circuit. See the attached letter.				
This condition has not evidenced itself before on engines				
with 24 blade impellers with steel inducers. It was not noted				
with 18-18 all aluminum impellers, using Bently-Nevada proximitors				
probes and extra signal conditioning, with the possible exception				
of PP9-11 installation in CE-28 at NASA Lewis Research Center				
last year. Eighteen and twenty-four blade steel inducers have				
near identical blade profile and location with respect to the				
pick-up.				
Small component and assembly differences may account for				
variations in inducer leading edge location, tip profile and				
running tip clearances. Since the inducer blade barely cuts				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

half the pick-up magnetic field, these variations may lead to differences in pick-up wave shape and amplitude, sufficiently large for marginal speed processing network performance.

Current and future engine builds will be surveyed to insure adequate engine/pick-up/speed circuit "system" performance. This cataloging of several engines will be necessary to make any design changes to insure adequate system performance for all builds.

A potential for gas generator overspeed exists unless speed sensing system has been qualified for operation during its initial run. A letter regarding this is attached.

B. W. Chapman

BWC/bjc

cc: P. R. Angell
G. A. Ball
T. Golec
J. Gross (3)
H. P. LeFevre
P. Kerwin (NASA)
R. Padovini
R. S. Rarey
E. Z. Trieskey



Inter Company Correspondence

To—Name & Department	Division	Date	Plant/Office	CIMS Number
J. V. Gross Power Plant Research-Development	Research & Materials Eng.	March 21, 1980	Chrysler Center	418-37-18
From—Name & Department	Division		Plant/Office	CIMS Number
H. P. LeFevre Power Plant Research-Electronics	Research & Materials Eng.		Chrysler Center	418-38-04

Subject: SPEED GOVERNOR PROBLEM - UPGRADED ENGINE

The upgraded G.T. engine (PP 216-C) in Cell 12S experienced speed control problems in the 80-90% range. This powerplant utilizes the first 18 bladed stainless steel inducer with magnetic pick-up speed sensing. The problem was investigated with two different ECU's and signal conditioning boards, as well as the two engine mounted G.G. speed pick-ups. It was found that the frequency to d-c converter (Bd. 6) lost pulses when the input to ICI dropped below the critical threshold level in the 80-90% speed range. When input resistor R13 was reduced from 4700 to 1000 ohms, the duty cycle of the squared wave form (TPI) improved and no drop out or threshold problems occurred. The engine operated successfully to 100% speed with this interim modification.

The upgraded G.T. engine was originally released with a stainless steel compressor inducer having 24 blades. (100% Ngg = 58,500 RPM = 23,400 Hz). A redesign of the compressor resulted in an 18 blade arrangement (100% Ngg = 58,500 RPM = 17,550 Hz). New compressor hardware consisted of aluminum inducers which utilized Bently-Nevada proximity probes for speed sensing. Similar speed sensing problems resulted due mainly to the frequency response limitations of the Bently probes which are rated to 10 KHz. The calibration of the frequency to d.c. converter has not been changed since both 18 and 24 bladed compressors are utilized. The correction is made in software for the 18 blade compressors, i.e., Ngg X 1.33.

The attached figures show eight oscilloscope photos with the applicable calibrations and conditions. Photos 4 and 8 represent the two speed pick-ups and processing signals at pin 4 of ICI and TPI of board 6 at 50% Ngg. The circuit loading of the pick-ups is clearly represented by voltage reduction and waveform alteration.

<u>Left P.U.</u>		<u>Rt. P.U.</u>
3.0 V p-p	Loaded	5 V p-p
6.5 V p-p	Unloaded	13 V p-p

The left pick-up had an installed gap of .021" while the right pick-up had an air gap of .012". Photos 5 and 6 represent engine operation at 90% Ngg with the left pick-up. Loss of governed speed control occurred at approximately this speed with ECU #111 and Bd. 6 S/N 111. Previous engine operation lost speed control with ECU #113 and Bd. 6 S/N 113 at 80% and at 85% with this ECU and Bd. 6 S/N 111. Note the improved signal at pin 4 of ICI and duty cycle change of TPI with R13 lowered to 1000 ohm as shown in photo 6. Photos 1 and 2 show engine operation at 75% Ngg. Photo 1 with the original value of R13 and photo 2 with R13

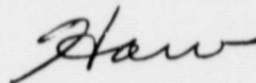
J. V. Gross
Speed Governor Problem - Upgraded Engine

March 21, 1980

reduced to 1000 ohms.

Engine operation at 50% Ngg is shown in photos 3 and 7 with the lowered value of R13. In Photo 3 the right pick-up is utilized and channel 2 shows the diode clamp waveform. In Photo 7 the left pick-up is utilized.

This speed sensing problem is the first instance for stainless steel inducers and magnetic pick-ups. Reducing the input resistance to pin 4 of IC1 has improved the input waveform to prevent threshold drop out and has improved the duty cycle of the squared waveform. Board 6 S/N 112 has this modification and will accompany PP 216-C to NASA Le R.C. for installation in their test cell SE-2. Subsequent engine builds will be checked along with existing vehicle installations.



H. P. LeFevre

HPLeF/lv

Attachment

cc: A. Billington
B. W. Chapman
T. Golec
J. Lunan
Ultra Electronics - 2
NASA File

Ch. 1, 5v/div
Ngg pickup (R/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

R13 = 4700 ohms

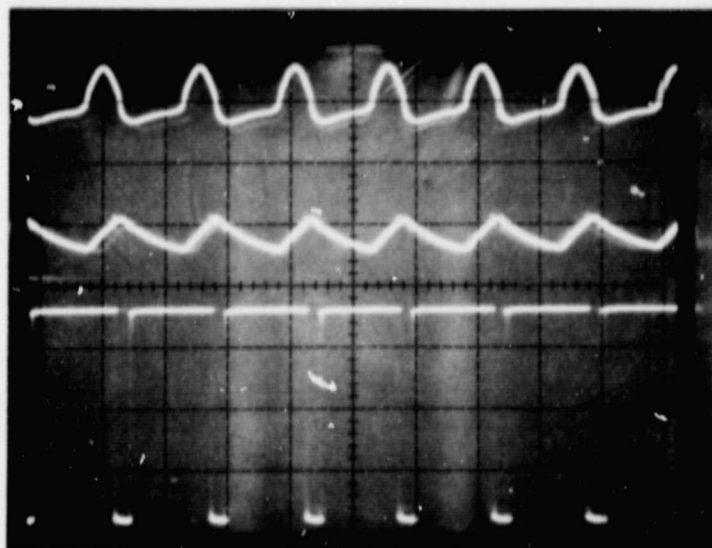


Photo 1

75% Ngg

0.05ms/div

Ch. 1, 5v/div
Ngg pickup (R/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

R13 = 1000 ohms

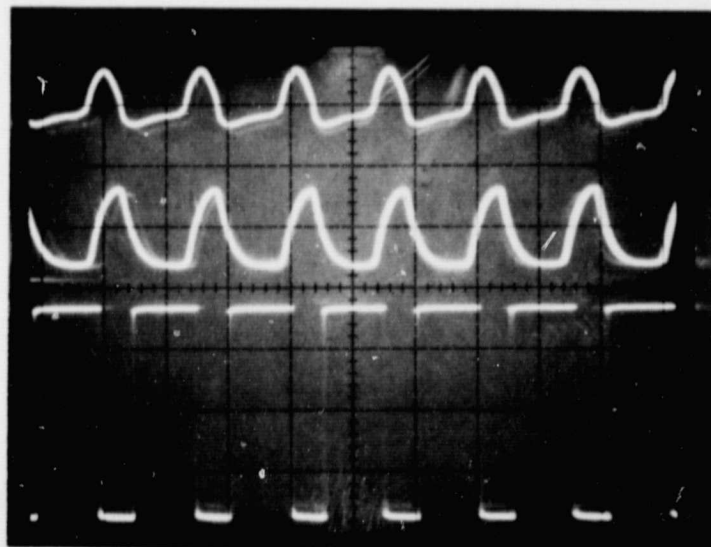


Photo 2

75% Ngg

0.05ms/div

Ch. 1, 5v/div
Ngg pickup (R/H) to ECU

Ch. 2, 1v/div
Diode clamp point A

Ch. 3, 5v/div
TP1, Board 6

R13 = 1000 ohms

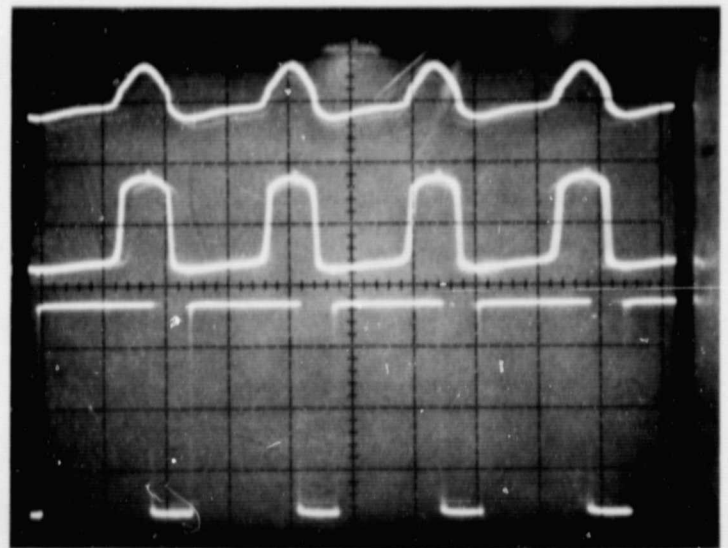


Photo 3

50% Ngg

0.05ms/div

Ch. 1, 5v/div
Ngg pickup (L/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

Ch. 4, 5v/div
Ngg pickup (R/H)

R13 = 4700 ohms

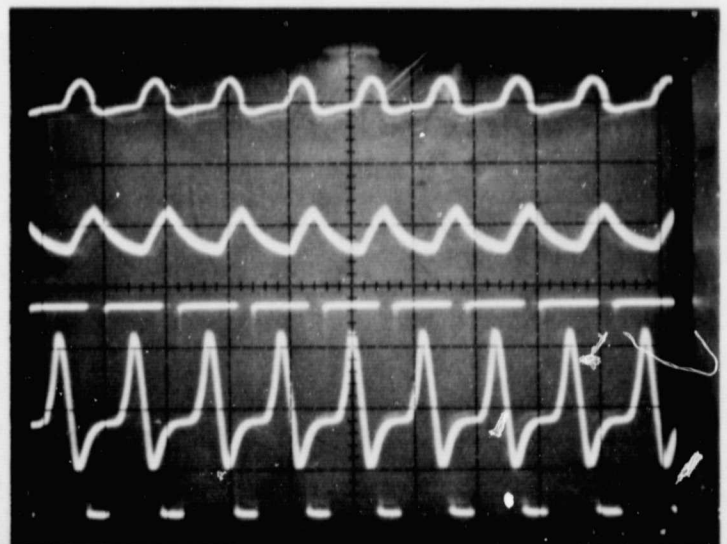


Photo 4

50% Ngg

0.1ms/div

Ch. 1, 5v/div
Ngg pickup (L/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

R13 = 4700 ohms

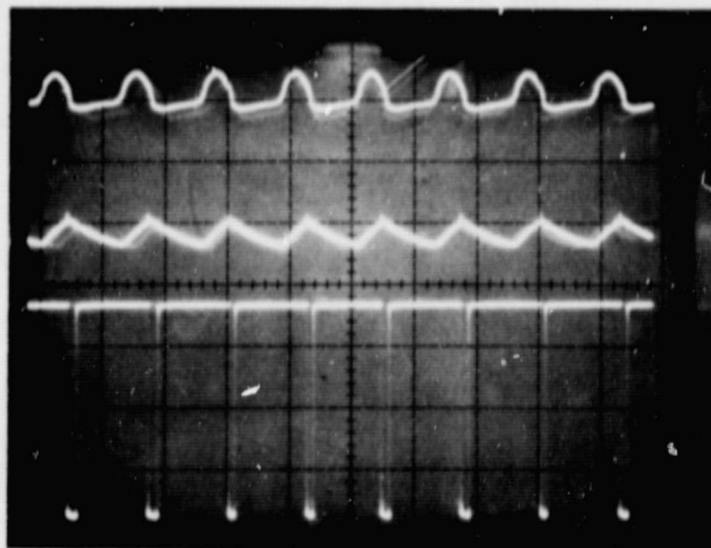


Photo 5

90% Ngg

0.05ms/div

Ch. 1, 5v/div
Ngg pickup (L/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

R13 = 1000 ohms

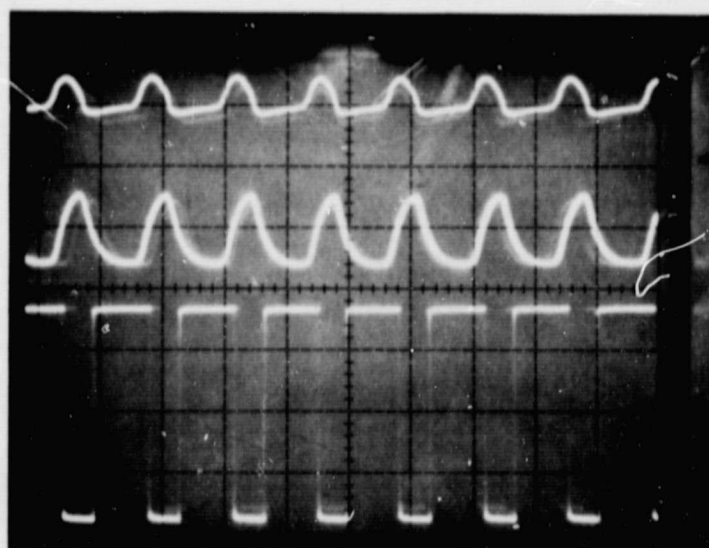


Photo 6

90% Ngg

0.05ms/div

Ch. 1, 5v/div
Ngg pickup (L/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

R13 = 1000 ohms

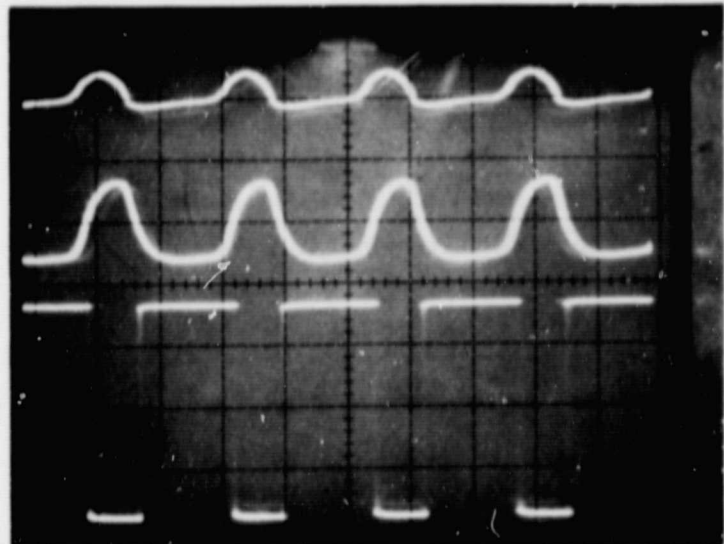


Photo 7

50% Ngg

0.05ms/div

Ch. 1, 5v/div
Ngg pickup (R/H) to ECU

Ch. 2, 1v/div
Pin 4, IC1, Board 6

Ch. 3, 5v/div
TP1, Board 6

Ch. 4, 5v/div
Ngg pickup (L/H)

R13 = 4700 ohms

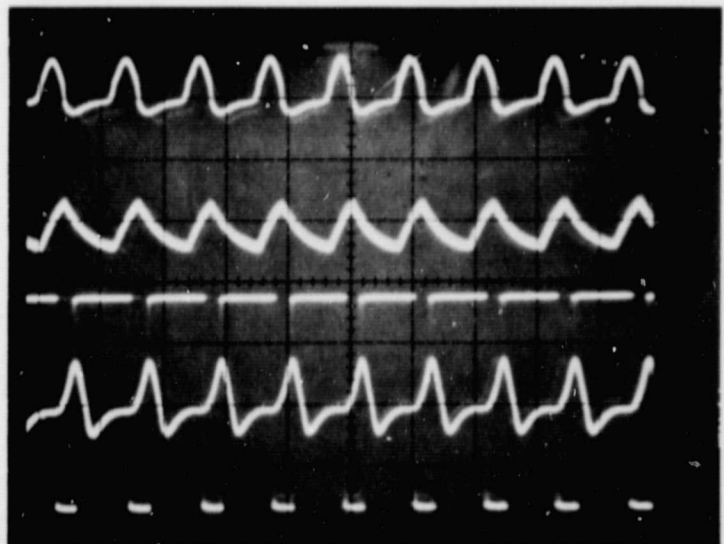


Photo 8

50% Ngg

0.1ms/div



Inter Company Correspondence

To-Name & Department	Phone No.	Date	File Code
		March 25, 1980	
J. V. Gross, Power Plant Research Dev.	E&PD	CC	418-37-18
From-Name & Department	Division	Plant/Office	CIMS Number
B. W. Chapman, Power Plant Research Dev.	E&PD	CC	418-37-18

Subject: A-926 SPEED PROCESSING SYSTEM QUALIFICATION

REFERENCE: Failure Report 82: ECU Speed Processing Board

Due to the nature of gas generator speed processing in the ECU, there is a potential for overspeeding the engine. To safeguard against overspeeding, IT IS RECOMMENDED THAT EVERY SPEED PROCESSING SYSTEM BE QUALIFIED DURING ITS INITIAL OPERATION FROM 60 TO 100% Ngg.

"Speed processing system" is defined here as any gas generator, speed pick-up, auxiliary speed conditioning circuit or leads, board 6, or ECU combination. "Qualify" is defined as the ability of the speed processing system to accurately reflect true speed up to 100% Ngg.

Any discrete change in speed processing system components requires a new qualification run. This would include new builds, adjustments to auxiliary speed conditioning circuits (all aluminum impellers), or selection of the spare pickup. Any change which might effect pick-up signal wave form, such as rotor, cover, or pick-up rework also requires a new qualification.

METHOD OF QUALIFICATION

1. Disconnect the fuel bleed solenoid valve from the engine electrical harness.
2. Accelerate slowly from 60 toward 100% Ngg.
3. If Ngg as displayed by the ECU drops suddenly by at least 5% while advancing the throttle, indicating a speed processing problem, go to Step 4, corrective action. Otherwise, go to Step 5.
4. Corrective action. Check and correct signal and conditioned wave forms or decrease inducer tip and leading edge clearance to pick-up. Return to Step 1.
5. If there is loss of throttle response at higher speeds, indicating a fuel system limitation, (see Point 6 on sketch) go to Step 6. Otherwise go to Step 13.
6. Go to one of the following Steps: 7, 11, or 12.
7. Go to one of the following Steps: 8, 9, or 10.

8. Recalibrate the fuel system. Return to Step 1.
9. Raise the acceleration fuel schedule. Return to Step 1.
10. Reduce bleed flow by 10 to 50%. Return to Step 1.
11. Observe the square wave duty cycle at test point 1 on Circuit Board 6 at maximum speed obtainable. If duty cycle is less than 75%, reconnect fuel bleed solenoid valve to engine electrical harness (on ECU control) and return to Step 2.
12. If an independent overspeed safety is available, reconnect the fuel bleed solenoid valve to the engine electrical harness (on ECU control) or to an external 12VDC supply. Return to Step 2.
13. Speed processing system is now qualified. Proceed with test plans.

EXPLANATION OF SKETCH

If the ECU speed count drops off while accelerating from Point 1, the ECU meters fuel at the acceleration fuel rate of the false ECU speed at Point 2.

If the bleed is open, the fuel level of Points 2 and 4 is sufficient to give a true engine speed corresponding to Points 4 and 5. If the bleed is closed, as it would normally be in an ECU defined accel mode, the engine fuel flow is great enough to accelerate the gas generator to Point 3. The stability point may surpass rotor burst speed if the false speed at Point 2 rises with true speed once the Board 6 duty cycle threshold has been reached. For these reasons, a reliable overspeed safety, independent of the ECU, or an open bleed are necessary for speed processing system qualification.

B. W. Chapman

BWC/bjc

cc: A. Billington
R. Schleicher
G. Stecher
L. Wagner - NASA Lewis Research Center
R. Wulf - NASA Lewis Research Center

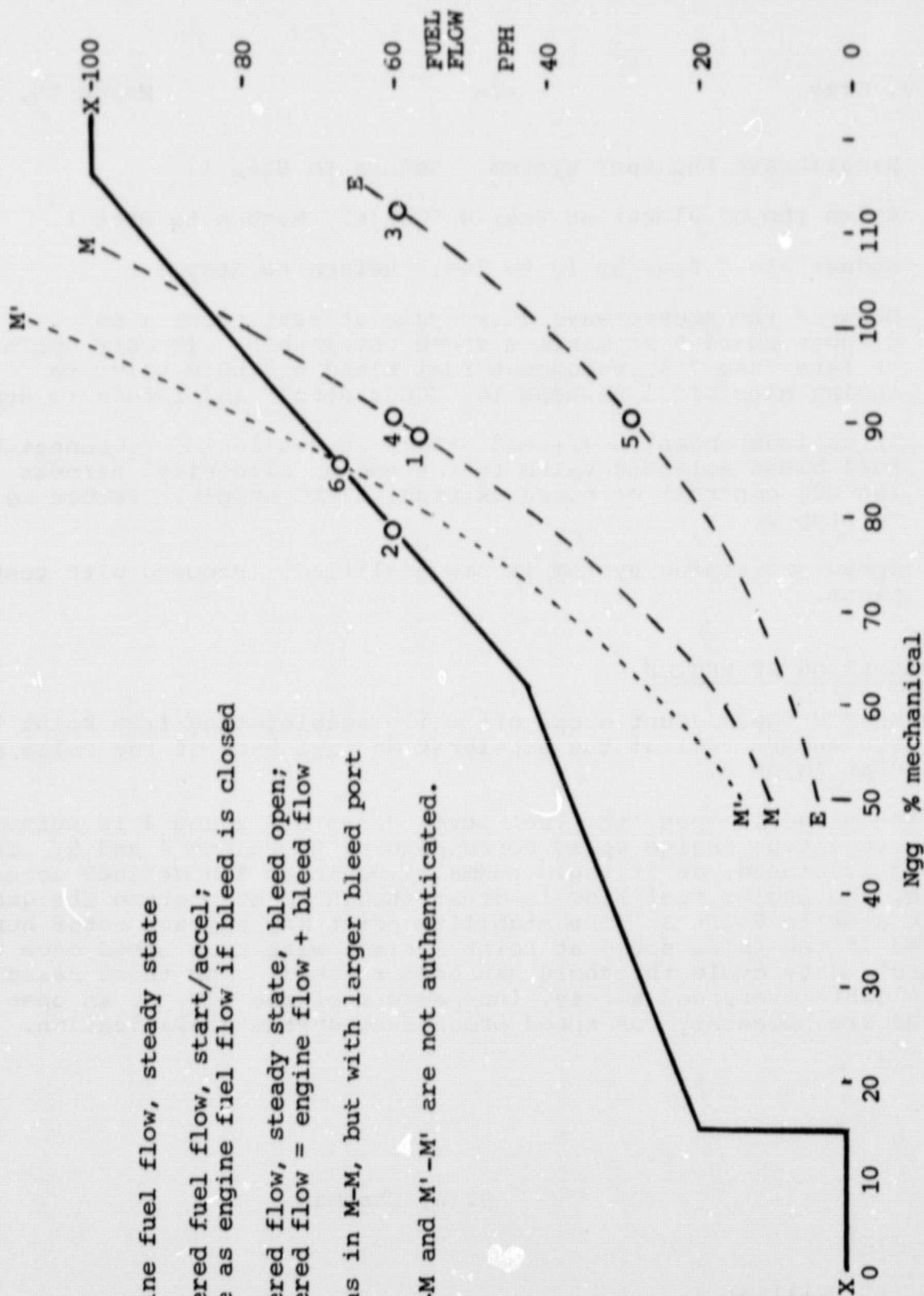
E-E Engine fuel flow, steady state

X-X Metered fuel flow, start/accel;
same as engine fuel flow if bleed is closed

M-M Metered flow, steady state, bleed open;
metered flow = engine flow + bleed flow

M'-M' as in M-M, but with larger bleed port

Lines M-M and M'-M' are not authenticated.



A-926 METERED AND ENGINE FUEL FLOWS
PP 2-16 B, steady state and acceleration modes
Engine fuel flow through torch excluded (~2½PPH)

NASA-Lewis Res. Center	MODEL A-926-1	DATE 3/19/80	ODOMETER (See Below)	SERIAL NO PP 9-11 J
PART FAILURES AND DEFICIENCIES 9520-926-83				
ISSUED TO DEPT NO. 9010 MR. C. E. Wagner				
PART NAME Assembly - Regenerator Core, Complete				
PART NUMBER 3814226 S/N 7				
MILES ON PART 169.4 hours on matrix, 17.0 hours on elastomer				
TYPE OF OPERATION Transient and steady-state performance testing at NASA, Cell CE-28				
BODY STYLE N/A				
DESCRIPTION OF FAILURE OR DEFICIENCY This was the third consecutive elastomer failure in this power plant and test cell (Reference: Failure Reports 78 and 81). Test conditions at the time of failure were 100% Ngg, 85°F inlet, and 1378°F T8. Prop shaft speed was 2600 RPM. When the characteristic losses of power and speed were observed, the engine was brought back to idle, a data point taken, and shutdown completed.				
On teardown, all the elastomer pads were found sheared, and the continued running after the failure had caused much of the remaining silicone to rub off in small fragments, contaminating the seal baseplates*. There was no evidence of adhesive failure at either the matrix or gear rim surfaces, and the matrix and its edge coating were intact. Secondary graphite seal breakage, as described in Failure Report 81, was noted. The rim area of the outer "D" graphite was heavily worn, without the characteristic polish normally found, while the corresponding area of the inner rim seal showed only traces of wear. Both these seals had been installed new with Core No. 7, 17 hours before the failure.				
FORM 220-6735 CHRYSLER CORPORATION P. P. & D. STAFF				

*The core had been repotted on February 11, 1980, using a new stock of Sylgard 186 elastomer.

On the two previous failures this heavy, rough wear pattern had been noted, but it had been attributed to the passage of broken matrix and/or rim cement past the rubbing surface. In the case of this failure, however, no source of contamination was found. The center area of the inner crossarm seal showed an unusually good contact pattern, indicating heavy bearing on the hub.

The above evidence suggests excessive clamping, such as would occur if the crossarm area of the engine housing bulkhead bowed outward. Bulkhead deflection had been documented and reported earlier in the program (Reference: Figures 20 and 21, 16th Quarterly), but no recheck has been made since the introduction of the housing baffles as shown on Drawing 4096591. These baffles improve BSFC by reducing T_2 to T_3 rise (Reference: Figures 11 - 14, 22nd Quarterly), and are incorporated in all powerplants at the time of retrofitting, including PP 9-11. While excessive core clamping has not been noted at Chrysler, a major difference in test philosophies may be responsible. At NASA most testing is done with the inlet temperature set at 85°F, whereas at Chrysler the inlet is kept as cold as possible (typically 40 - 50°F). This results in cycle or "match" temperatures on the order of 100 - 150°F higher at NASA, with corresponding increases in housing temperature. This difference may be just enough to deflect the bulkhead beyond the regenerator build clearance (typically 0.040 in.), resulting in excessive torque loads and elastomer failure. Also, at Chrysler testing at 100 percent is kept to an absolute minimum - less than one percent of total operating time - to minimize risk to scarce development hardware.

A second area of concern, considering the high regenerator failure rate in CE-28, is the capability of the cell's new dynamometer of inducing step-changes in output shaft (and hence, regenerator) speed. Rapid drive shaft accelerations, especially under high clamping load conditions, could conceivably overload and shear the elastomer. Room 4 at Chrysler, where PP 9-11 ran 98 hours before delivery to NASA, also has a motoring dynamometer, but maximum typical prop shaft accelerations are on the order of 1000 RPM per second during start-up, with changes during running made even more slowly.

While the recommendations of Failure Report No. 81 are still valid, the following additional precautions are urged:

1. Until such time as bulkhead deflections in the retrofitted engines can be documented, regenerator seal clearance should be increased to 0.050 - 0.060 inch.
2. NASA should investigate ways of programming higher inertia settings into the CE-28 dynamometer, to reduce acceleration loads on regenerator and rotor systems.

A. Billington
A. Billington

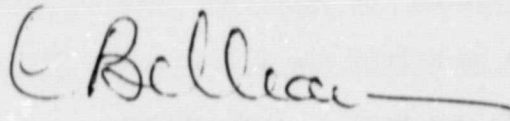
AB/bjc

cc: P. R. Angell, G. A. Ball, J. Corwin, F. Hagen, T. Golec, J. V. Gross, R. Padovini, R. S. Rarey, E. Z. Trieskey, P. Kerwin

TRUCK NO.	MODEL	DATE	GODMETER	SERIAL NO
Car No. 385	A926-1	6/23/80	547.4	PP4-15I
PART FAILURES AND DEFICIENCIES 7340-926-84				
ISSUED TO DEPT NO 7340 MR C. E. Wagner				
PART NAME Wheel - Compressor Turbine				
PART NUMBER 4096402 S/N 155				
Hrs.				
XXX HRS ON PART 49.5 (6.8 hrs test cell, 42.7 vehicle)				
TYPE OF OPERATION				
BODY STYLE				
DESCRIPTION OF FAILURE OR DEFICIENCY Routine Zyglo of CTW 155 following teardown of				
PP4-15I (Car 385) revealed excessive sharp indications at the root fillet				
pressure surface on most of the blades near the leading edge.				
Neutralizing the penetrant did not completely clean away the fluid				
and it bled back from the fillet areas indicating crack possibilities. The				
suction side was free of indications.				
Microscopic examination revealed excessive porosity - possibly crack				
indications. Also evident were small parting lines and axial "bumps" the				
length of the parting lines indicative of the water soluble pattern process				
utilized for the flow path surfaces.				
Based on the following analysis, the wheel was removed from vehicle				
service and held for limited-test cell use.				
The wheel is one of a batch of five received from Howmet:				
<u>S/N</u>	<u>Location</u>	<u>Status</u>		
152	Amt - Cut Up	Tips burned - Failure Rpt. #68		
153	Build UP - GG #10			
154	PP3-13 (Rm 12S)	Shaft Dynamics		
155	Amt - Hold			
156	NASA PP2-16			

Since CTW 152 is not usable it was employed as a test piece to evaluate the wheel in question. Visually, the fillets looked similar although the areas did not look as serious through the microscope nor were the Zyglo indications as numerous or as sharp as Wheel 155. The wheel was microsectioned and examined at .020 inch axial increments from the leading edge. Most sections showed "notches" of varying severity at the blade root where Zyglo indications had been found. A crack extending to a depth of 0.014" was found at the root of a blade approximately 0.040" from the leading edge. Additional grinding to a depth of 0.200" revealed connected shrinkage porosity extending radially to a depth of 0.500"; with further grinding to 0.260", the shrinkage defect was found to have developed into a crack emerging, at the surface, near a blade root.

Although overheating of CTW 152, prior to failure, might have enhanced the apparent severity of the casting defects, the evidence points to a potentially shortened life in normal service for wheels with similar casting defects. Limited service, with frequent inspection, is then recommended for Wheel S/N 155.



C. Belleau

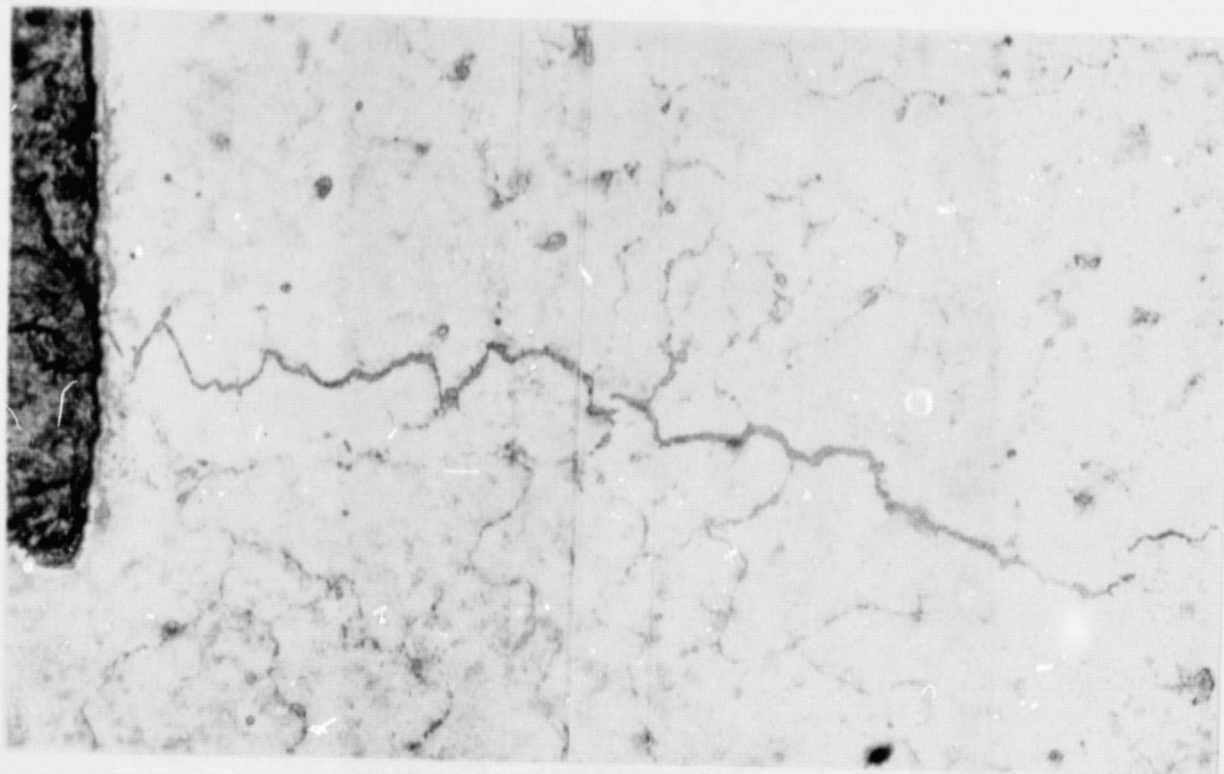


E. Kohl

/bjc

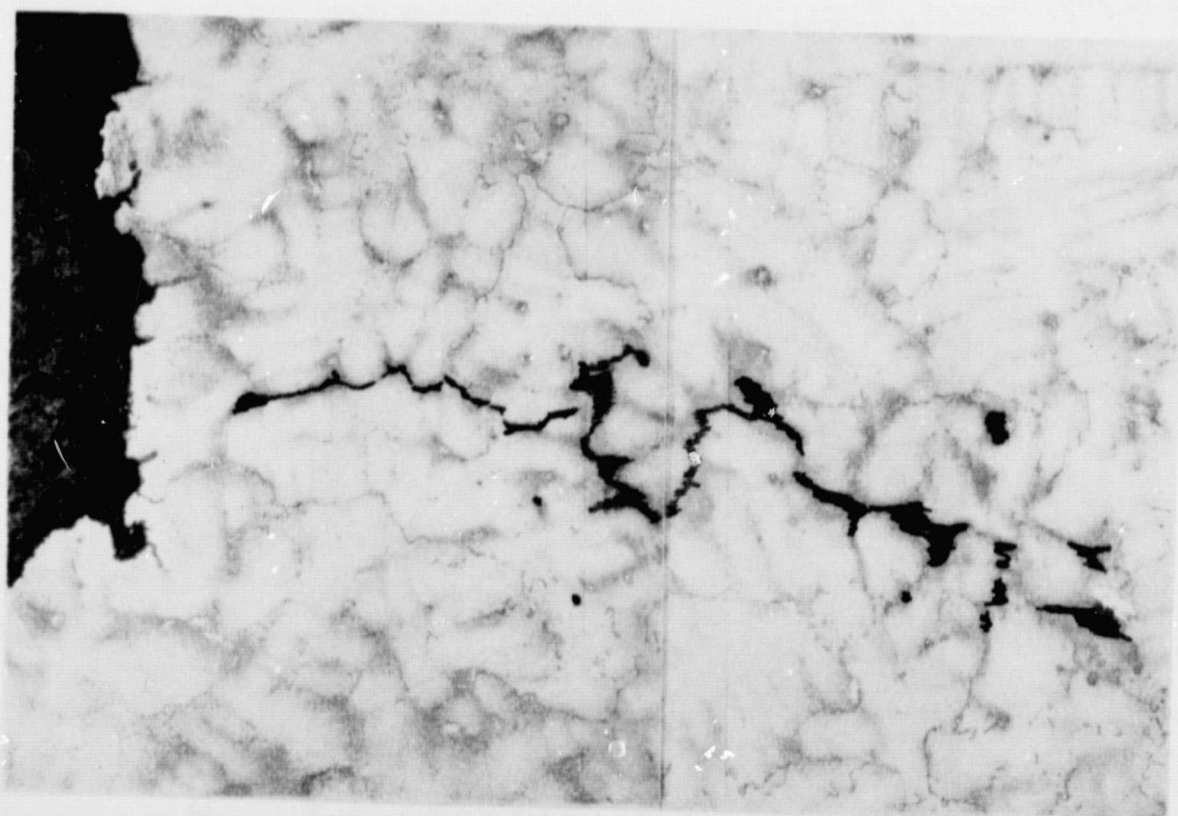
2 enclosures

cc: J. M. Corwin
T. Golec
J. V. Gross (3)
P. Kerwin (NASA)
R. C. Pampreen
R. F. Pauley



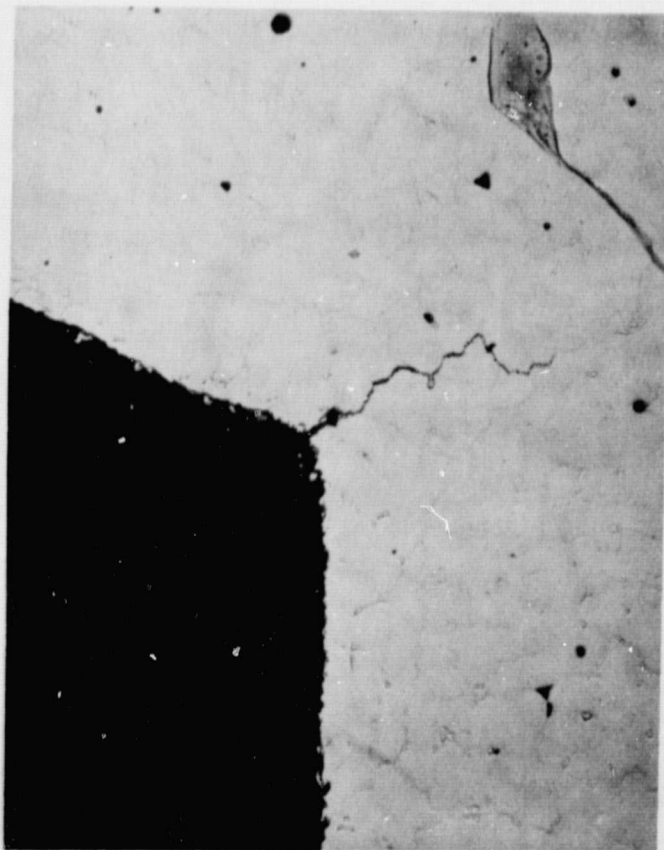
DEPTH: 0.260"

X100



DEPTH: 0.200"

X100



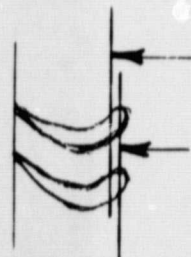
DEPTH: 0.040"

100X



DEPTH: 0.100"

100X



METALLOGRAPHIC SECTIONS

CAR NO.	MODEL	DATE	ODOMETER	SERIAL NO.
385 (U-1)	A-926	6/30/80	547.4	Eng. 2 PP 4-15 I
PART FAILURES AND DEFICIENCIES 7340-926-85				
ISSUED TO: DEPT. NO. 7340 MR. C. E. Wagner				
PART NAME: Engine Housing - Complete				
PART NUMBER: 3814204 (Housing Machining SN 4, PTN Support SN 3)				
MILES ON PART: 365 miles on damaged PT wheel 3813807-209; 42.7 hours; 472 starts, from Build G vehicle.				
DESCRIPTION OF FAILURE OR DEFICIENCY: The engine was removed from vehicle U-1 for inspection of power turbine assembly to determine the source of gear noise. The power turbine wheel had rubbed between the seven and twelve o'clock positions, as viewed from the rear. Runouts of the shroud showed it to be shifted downward .0065 in. relative to the power turbine pilot. Additionally the cold pilot in the housing for the PTN pilot has shifted .013 in. to the left toward the rub area. The PTN support hot and cold pilots are .008 in. dia. out of round and very tight on the engine housing pilots. The ENGINE HOUSING BULKHEAD engine housing bulkhead is .007 rearward on the left side.				
This engine housing had been outfitted with the latest bulkhead flow deflectors. A new reduction gear assembly will be used for Engine 2. Dual interwoven springs will be installed in the PT wheel journal bearing to decrease bearing complaine and rotor displacement.				
By: J. V. Gross and B. W. Chapman cc: J. M. Corwin P. Kerwin (NASA) R. C. Pampreen T. Golec T. Nogle N. W. Sparks E.Z. Triesky				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE. AND MAIL TO DATA SECTION, DEPARTMENT 870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION ENGINEERING STAFF				
ROYAL MCBEE - DETROIT				

TRUCK NO. Car # 386 (U-2)	MODEL A-926	DATE 8-25-80	ODOMETER 6494	SERIAL NO. PP 10-14 AG
PART FAILURES AND DEFICIENCIES 7830-926-86				Page 1
ISSUED TO: DEPT. NO. 7830 MR. C. E. Wagner				
PART NAME vehicle				
PART NUMBER 3814801				
442.5 hours				
TYPE OF OPERATION: Display, D.O.E.; shipment by commercial carrier to and from Iowa.				
BODY STYLE:				
DESCRIPTION OF FAILURE OR DEFICIENCY: Damages incurred during shipment:				
1) Transmission mount screw missing				
2) Right side engine mount rubber failure				
3) Starter cable off, stud touching air filter housing				
4) Heater hot gas supply tubing weld broken at gas valve flange				
5) Sheet metal cracks (approximate lengths, locations)				
left side engine compartment: 8", ECU tray upper along existing weld				
right side engine compartment:				
6" wheel well, heat exchanger, rear				
6" wheel well, heat exchanger, front				
1" wheel well, suspension clearance front				
3" battery tray lower, rear				
1" (x2) battery tray upper (old?)				
1" (x2) battery tray front, lower				
2" wheel well, front near suspension access panel				
9" battery tray lower (broken weld)				
2" bumper support bracket, outboard				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-3735		CHRYSLER CORPORATION P. P. & D. STAFF		

PART FAILURES AND DEFICIENCIES
dated 3-25-80

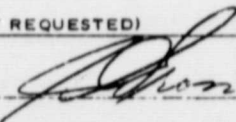
7830-926-86

Items 1, 3 and 4 have been repaired so that the car can be driven.
The remaining items will be repaired under future service contract funding.

By: Bruce Chapman

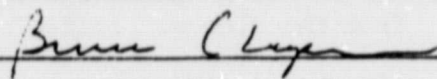
cc: J. M. Corwin
T. Golec
J. V. Gross (3)
R. Padovini
E. Z. Trieskey
P. Kerwin (NASA)
R. F. Pauley
T. D. Nogle
N. W. Sparks

TRUCK NO. 469(U-4)	MODEL A-926	DATE 9-26-80	ODOMETER 57.6	SERIAL NO. PP 4-15 J
PART FAILURES AND DEFICIENCIES 7830-926-87				
ISSUED TO: DEPT. NO. 7830 MR. C.E. Wagner				
PART NAME: Electronic Control Unit				
PART NUMBER: 3814546 SN 5; Ultra Model C4E86, serial no. 113				
MILES ON PART: 484 miles in Car 385 (U-1), 57.6 hours; 85.1 hours total				
TYPE OF OPERATION: Vehicle				
Discovered during car build-up, program bench check.				
BODY STYLE:				
DESCRIPTION OF FAILURE OR DEFICIENCY: Loss of light off sensing and cranking timer safeties.				
Excessive 'noise' observed in T5 rate of rise signal storage. Cranking timer voltage signal trips appropriately but fails to disengage starter.				
Problems remained after interchanging T/C, WS&I, and GCA circuit boards with ECU SN3, which exhibited related malfunctions but with different symptoms.				
ECU SN5 returned to service with these deficiencies. Determination of failure source and repair to be undertaken when both manpower and vehicle are available concurrently. See 9-26-80 repair request for details.				
VEHICLE TEST SECTION INSPECTION: (LAB INSPECTION AND REPORT REQUESTED) <i>Bruce Chapman</i>				
BRUCE CHAPMAN 12-19-80				
cc: J. Corwin				
T. Golec				
J. Gross (3)				
P. Kerwin-NASA				
H. LeFevre				
T. Nogle				
R. Padovini				
R. Pauley				
N. Sparks				
E. Trieskey				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO. Car 649 U-3	MODEL A-926 Gas Turbine	DATE 10-17-80	ODOMETER 332	SERIAL NO. PP8-10M
PART FAILURES AND DEFICIENCIES 7830-926-88				
ISSUED TO: DEPT. NO. 7830 MR. C. E. Wagner				
PART NAME Vehicle Complete				
PART NUMBER				
MILES ON PART 332.0				
TYPE OF OPERATION Vehicle Demonstration/Display				
BODY STYLE Special modified 1977 LeBaron Coupe				
DESCRIPTION OF FAILURE OR DEFICIENCY The engine air/oil pump system was not turning during cranking tests. The electro-magnetic clutch was found inoperative due to lack of power. A non-released boot clamp had worn thru the boot and power leads, shorting to ground causing the wires to burn thru. Sufficient coil lead lengths remained to allow extensions to be used restoring the original coil to service.				
Total estimated shipping distance in North America has increased to 18,322 miles (total distance in the world is now 24,322 miles).				
VEHICLE TEST SECTION INSPECTION: (LAB INSPECTION AND REPORT REQUESTED)				
 J. V. GROSS				
cc: T. Golec				
J. V. Gross (3)				
R. Padovini				
E. Z. Trieskey				
P. Kerwin (NASA)				
R. F. Pauley				
T. D. Nogle				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO. Car 649 U-3	MODEL A-926 Gas Turbine	DATE 9-24-80	ODOMETER 318.0	SERIAL NO. PP8-10M
PART FAILURES AND DEFICIENCIES 7830-926-89				
ISSUED TO: DEPT. NO. 7830 MR. C. E. Wagner				
PART NAME Vehicle Complete				
PART NUMBER				
MILES ON PART 318.0				
TYPE OF OPERATION: Vehicle Demonstration/Display				
BODY STYLE Special modified 1977 LeBaron Coupe				
DESCRIPTION OF FAILURE OR DEFICIENCY: The vehicle returned from California where it was stored for four months following an exhibit at Sacramento.				
The following discrepancies were noted:				
- The right engine mount had failed allowing the regenerator cover to rest on the engine mount bracket.				
- Rear support bolts for transmission were loose.				
- Radiator yoke at lower right is pushed rearward and up.				
- Filter box outlet is distorted and allows air to bypass the filters.				
- Fiberglass damage to underside of air dam.				
- Oil cooler fan mounts sheared.				
- The linerless insulation in the burner cap is loose. As a result it has fretted approximately .060 in. material radially around the spacer tubes and fretted approx. .050 in. axially behind mixer pads. Examination showed the insulation has not been force behind the retaining wire mesh sections.				
Total estimated shipping distance in North America has increased to 15,322 miles (Total distance shipped in the world is now 21,322 miles).				
J. V. GROSS				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

cc: T. Golec, J. V. Gross(3), R. Padovini, E. Z. Trieskey, P. Kerwin (NASA)
R. F. Pauley, T. D. Nogle

TRUCK NO. NASA Lewis R.C. Cell CE-28	MODEL A-926	DATE 11-24-80	ODOMETER -	SERIAL NO. PP 9-11 H
PART FAILURES AND DEFICIENCIES 7830-926-90				
ISSUED TO: DEPT. NO. 7830 MR. C. E. Wagner				
PART NAME: Power Turbine Nozzle Actuator				
PART NUMBER: 40966650 Serial Number 3				
MILES ON PART: Hours not known, in service June, 1979 - August, 1980				
TYPE OF OPERATION: NASA Lewis, transient test cell CE-28				
BODY STYLE:				
DESCRIPTION OF FAILURE OR DEFICIENCY: Actuator shaft bore in housing adaptor galled badly.				
May have caused or contributed to poor nozzle response. Aluminum bore has				
been deburred and adaptor has been anodized to resist galling.				
Additional repairs have been made to overcome three minor deficiencies:				
external leakage at null valve seal, loose force motor push rod (yielding				
misindexed "null"), and loss of position feedback signal (probably caused in				
handling or transit).				
 Bruce Chapman				
VEHICLE TEST SECTION INSPECTION: (LAB INSPECTION AND REPORT REQUESTED)				
cc: J. Corwin T. Nogle				
T. Golec R. Padovini				
J. Gross (3) R. Pauley				
P. Kerwin NASA N. Sparks				
H. LeFevre E. Trieskey				
C-422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

TRUCK NO.	MODEL	DATE	ODOMETER	SERIAL NO.
	A-926-1	1-8-81	N/A	PP9-11 NASA-Lewis
PART FAILURES AND DEFICIENCIES 7830-926-91				
ISSUED TO: DEPT. NO. 7830 MR. C. E. Wagner				
PART NAME Air Bearing - Gas Generator Rotor				
PART NUMBER 3813871 S/N 6-2				
MILES ON PART 153.1 Hrs., 369 Starts (NASA 147.5 Hrs., 363 starts)				
TYPE OF OPERATION Steady State General Development Testing.				
BODY STYLE				
DESCRIPTION OF FAILURE OR DEFICIENCY				
<p>The Gas Generator Assembly seized while at 87% Ngg. Inspection showed the air bearing had seized. The following discrepancies were noted by NASA and/or Chrysler personnel during inspection of the various parts.</p> <p>- <u>Air Bearing</u>/Air Bearing Sleeve seized together. The air bearing ears and middle seal sustained damage as the combined pieces had to be forced out. The air bearing was slit axially diametrically opposed to remove it from the sleeve. Initial visual inspection revealed some pieces of smooth foil remain.</p> <p>Additional Metallurgical comments are appended.</p> <p><u>Air Bearing Sleeve</u> - Rear half of journal is galled and/or plated with debris. The thrust face for the oil bearing has a new not run appearance. A brown hard deposit is on the slinger OD and immediately forward of the slinger on the small diameter.</p> <p><u>Compressor Rotor</u> (all aluminum) - Very dirty upon receipt from NASA. This</p>				
CIMS 422-01-09			See pg. 2.	
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

problem has been seen consistently from previous gas generator assemblies. The accompanying photos show the relative dirt accumulation compared to a virgin compressor. The rotor sustained face tip and eye O.D. rubs. Zyglo showed a radial back face crack at the O.D. which radiates in an arc thru one blade.

The back face shows surface displacement across the crack, no obvious signs of mechanical damage exist. This rotor has been machined from a forged billet which has been x-rayed and zyglod initially and approved. The rotor was zyglod upon receipt, tested-modified, and Rezyglod prior to assembly into PP 9-11. The aluminum leading edges of the main and splitter vanes are somewhat rough suggesting erosion. Some impact craters (by larger particles) are visible under higher magnification.

Turbine Wheel - 151 - There are possible crack indications at the leading edge root fillet. These are similar to turbine wheel 155 (Ref. Failure Report 7340-926-84 and appended Speedi Memo).

The wheel O.D. is .011 in dia. smaller over approximately half the periphery. Runout in this area gradually increases to a maximum at the mid point. Runout over the remainder of the wheel is virtually zero. The wheel seal journal diameter exhibits heavy rubs indicating contact with the carbon seal steel cartridge. The heaviest point is coincident with the shortest blade O.D. area. The replacement wheel #155 exhibits similar root fillet indications. This wheel is limited service with frequent inspections as outlined in the previously referenced Failure Report.

J. V. GROSS

mab

cc: C. Belleau
J. Corwin
T. Golec
J. Gross (3)
P. Kerwin - NASA
T. Nogle
R. Padovini
R. Pauley
N. Sparks
E. Trieskey

REFER TO

☐ YOUR
☐ LETTER
☐ SPEEDIMEMO
☐ PHONE CALL
☐

☐ MY
☐ MEMO
☐ TELEGRAM
☐ CONFERENCE

SPEEDIMEMO

DATE

1/23/81

TO J. V. GROSS

LOCATION DEPT 7830 - LAB

FROM C. BELLEAU

LOCATION DEPT 7830 - AMT

OF (DATE)

SUBJECT

AIR BEARING FAILURE (S/N 6-2)

MESSAGE

Gas generator seized at 153 hrs. Prior to failure the smooth and corrugated foils had moved partially out of the cartridge. Due to the extent of the damage caused by the seizure the cartridge had to be slit to separate it from the journal. (Figs 1 through 3). Examination at low magnification revealed a short length of the foil attachment and bump block had escaped destruction (Figs 3 & 4). The fractured end of the smooth foil protruding from the rear of the bearing and the remaining weld nuggets and fractured smooth foil on the bump block, at the front of the cartridge, suggest that the primary failure occurred by fracture of the smooth foil at the spot weld line. That section of the cartridge was cut out for fractography. A small portion of the primary fracture face was found intact except for heavy edge deformation where rubbing by the journal had occurred. SEM fractographic analysis (Figs 5 & 6) of the small undamaged area showed the fracture mode was largely cleavage. Although no clear evidence of striations could be found, it is probable that fatigue was the primary cause of fracture of the smooth foil at the spot weld line.

(Ref Part Failure & Def. Report - 7830-926-92)

SIGNED

C. Belleau

DATE

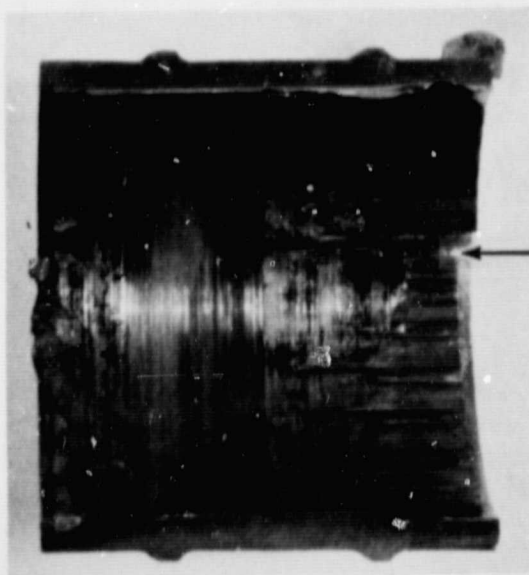
AIR BEARING (S/N 6-2)



Figure 1. Front



Figure 2. Rear



Bump Block

Figure 3.

Top edge deformation

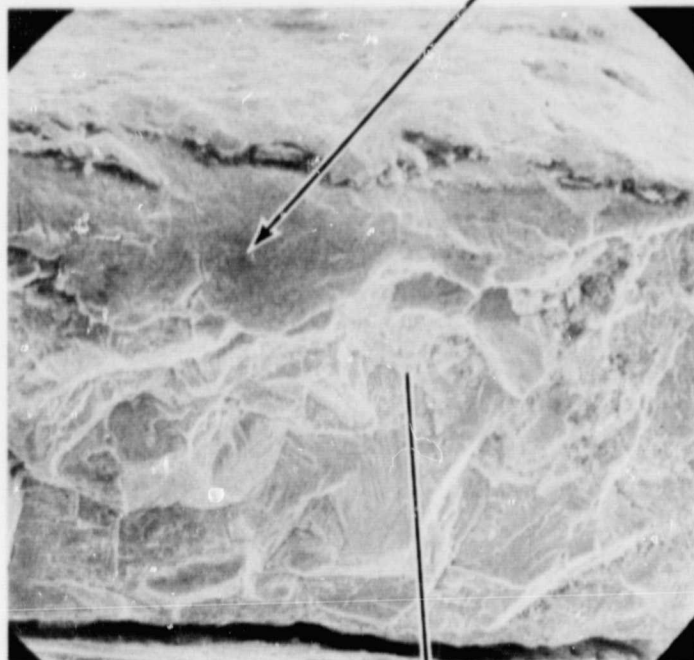


Figure 5.

(800X)

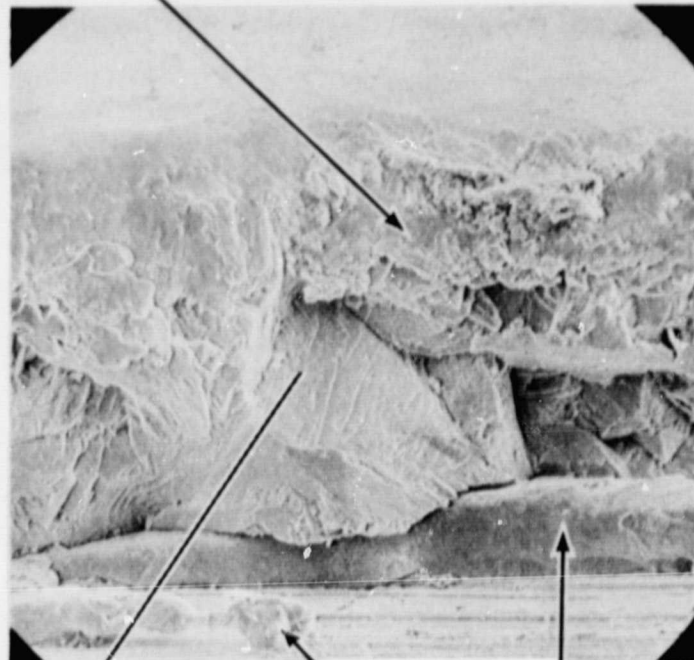


Figure 6.

(600X)

Weld
Expulsion

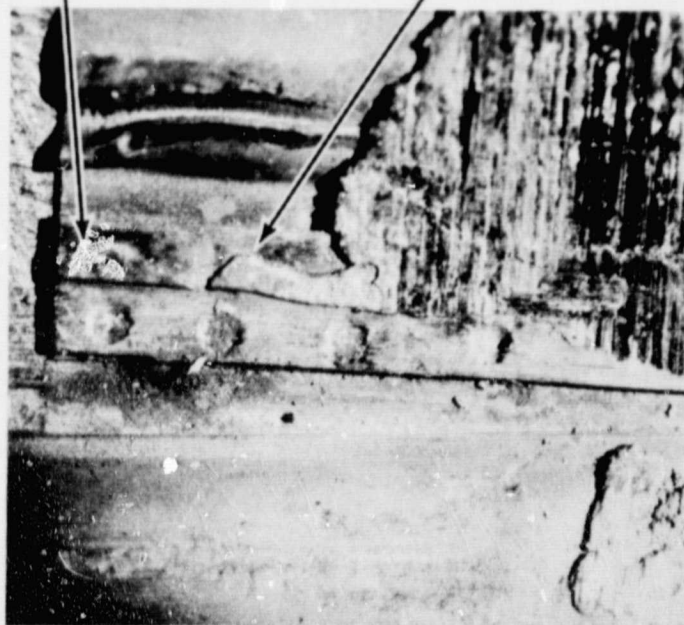
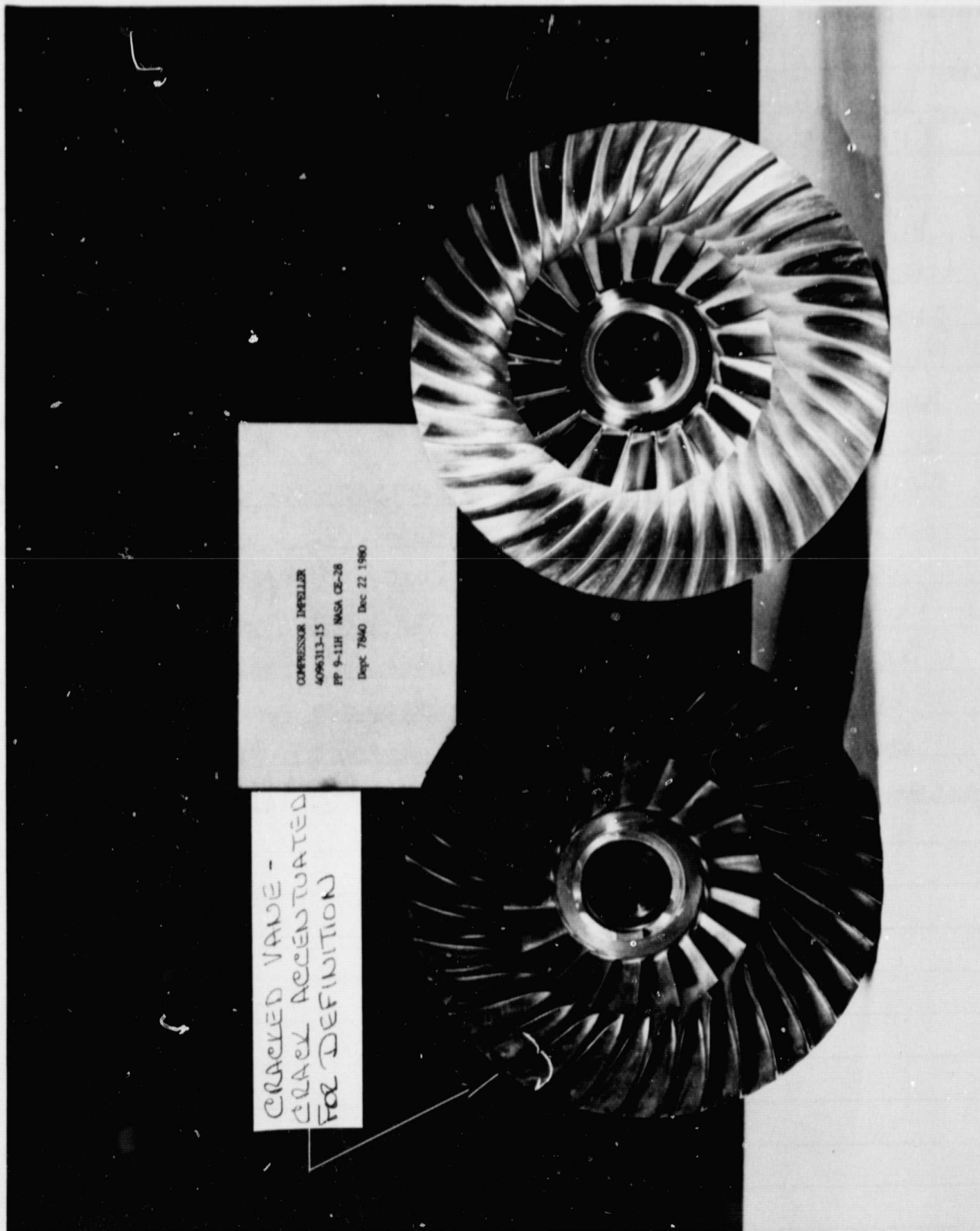


Figure 4. Foil and bump block.



CRACKED VAUVE -
CRACK ACCENTUATED
FOR DEFINITION

COMPRESSOR IMPELLER
4096313-15
PP 9-11H NASA CE-28
Dept 7840 Dec 22 1980

REFER TO

☐ YOUR
☐ LETTER
☐ SPEEDIMEMO
☐ PHONE CALL
☐ MY
☐ MEMO
☐ TELEGRAM
☐ CONFERENCE

SPEEDIMEMO

DATE

1/12/81

TO

V.V. GROSS

LOCATION

DEPT 7830 LAB

FROM

C. BELLEAU

LOCATION

DEPT 7830 AMT

OF (DATE)

SUBJECT

CTW S/N 151

MESSAGE

(PP 9-11, AIR BEARING FAILURE, TOTAL HRS 169.4, 147.5 hrs since previous inspection)
 wheel was fluorescent penetrant inspected. Zygo indications at several blade roots, near the leading edge, were revealed. Those were not evident at the previous inspection. Prior metallographic investigation of a wheel with similar indications had uncovered cracks, shrinkage porosity and "notches" at blade roots (S/N - 152. Ref. PART FAILURE & DEFICIENCIES REP. #7340-926-84, 6/23/80). The evidence pointed to a potentially shortened service life. In view of the above findings it appears necessary to monitor the behavior of the blade root defects by frequent inspection and anticipate premature failure. Limited service, not exceeding 20-30 hrs of running between Zygo inspections, is recommended for wheel S/N 151.

ORIGINATOR - DO NOT WRITE BELOW THIS LINE

SIGNED

REPLY

MODEL	A-926-1	DATE	1-8-81	ODOMETER	N/A	SERIAL NO	PP2-16 NASA-Lewis
PART FAILURES AND DEFICIENCIES 7830-926-92							
ISSUED TO	DEPT NO.	7830		MR.	C. E. Wagner		
PART NAME	Air Bearing - Gas Generator Rotor						
PART NUMBER	3813871 S/N 21-1						
MILES ON PART	55.1 Hr 95 starts (NASA:26.4 Hrs, 55 starts)						
TYPE OF OPERATION	Steady-state General Development Testing						
BODY STYLE	N/A						
DESCRIPTION OF FAILURE OR DEFICIENCY	<p>The gas generator was disassembled at NASA to determine cause of tight shafting. The smooth foil section was found protruding forward. Closer inspection showed a complete fracture of the smooth foil thru the spot weld area. This bearing utilized the latest spot weld technique. Additional metallurgical inspection is in process to determine the exact cause of the failure. A speedimemo discussing the failure mode with photos is appended.</p> <p style="text-align: right;"><i>J. V. Gross</i> J. V. GROSS</p>						
cc:	C. Belleau J. Corwin T. Golec J. Gross (3) P. Kerwin - NASA T. Nogle R. Padovini R. Pauley N. Sparks E. Trieskey						
CIMS 422-01-09 (PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 8870, PROVING GROUND) FORM 220-6735 CHRYSLER CORPORATION P. P. & D. STAFF							

REFER TO

☐ YOUR
☐ LETTER
☐ SPEEDIMEMO
☐ PHONE CALL
☐

☐ MY
☐ MEMO
☐ TELEGRAM
☐ CONFERENCE

SPEEDIMEMO

DATE

1/12/81

TO J. V. GROSS

LOCATION DEPT 7830 - LAB-

FROM C. BELLEAU

LOCATION DEPT 7830 - AMT

OF (DATE)

SUBJECT

AIR BEARING FAILURE (S/N 21-1)

MESSAGE

REF - PART FAILURE & DEFICIENCIES REP. #7830-926-92, 1/8/81

Fracture of the smooth foil was found to extend the full width of the foil at the spot weld line. (Figs 1 & 2). Scanning electron microscope fractographic analysis revealed evidence of fatigue failure originating between weld nuggets at the rear of the bearing. The fracture appears to have followed the contours of most weld nuggets in propagating across the foil, leaving them intact and attached to the bump block. (Figs 3 through 8) Contact damage or deformation at the fracture occurred after foil failure.

ORIGINATOR - DO NOT WRITE BELOW THIS LINE

SIGNED

C. Belleau

REPLY

SIGNED

DATE

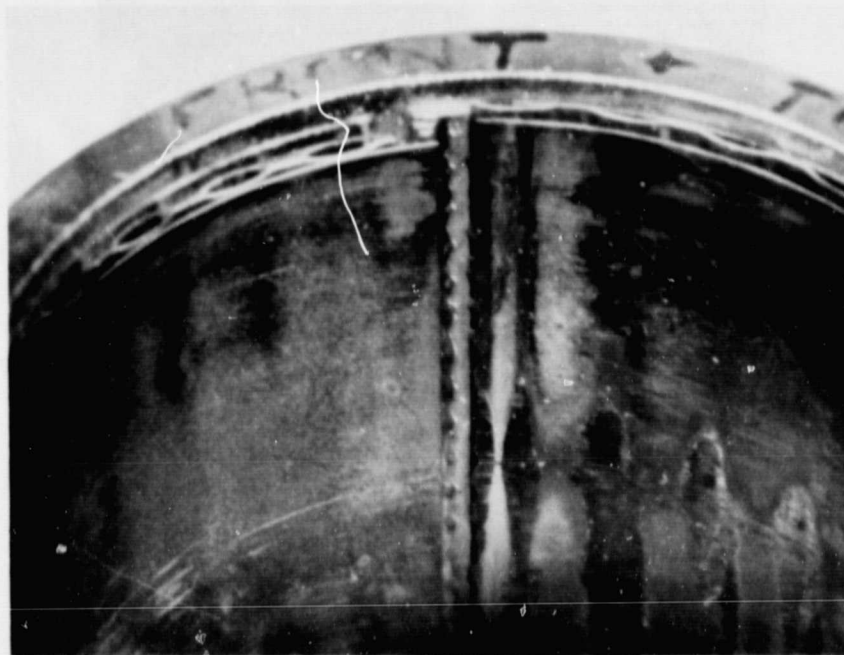


Figure 1
Front of Bearing



Figure 2
Rear of Bearing

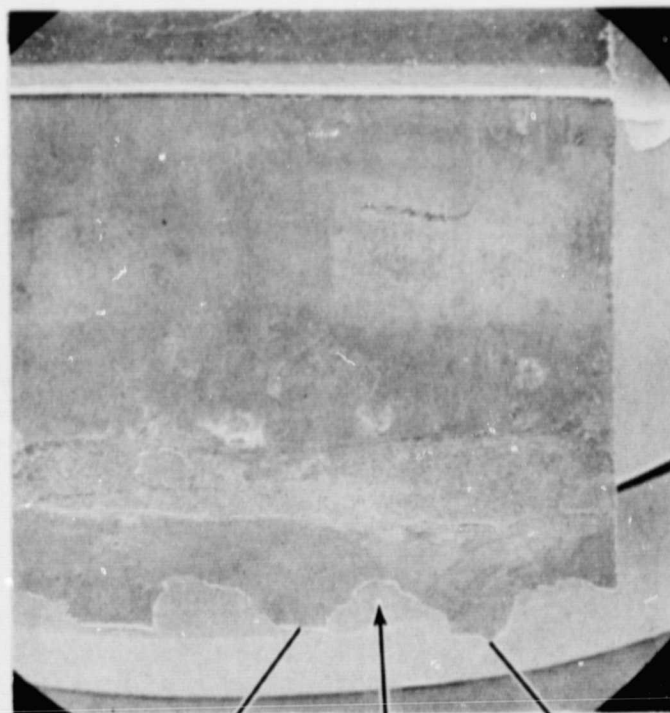
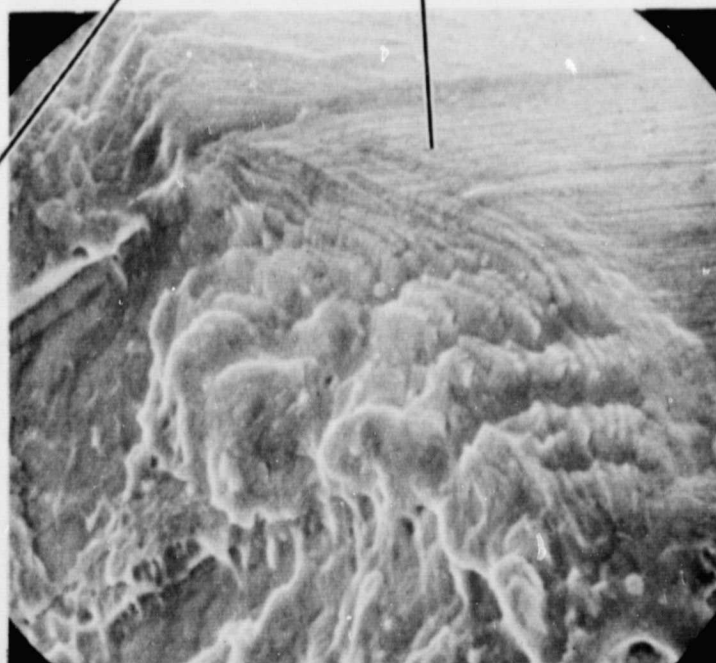


Figure 3 10X
Rear of Bearing



Area A

Area B

Figure 4 3000X
Fatigue Striations

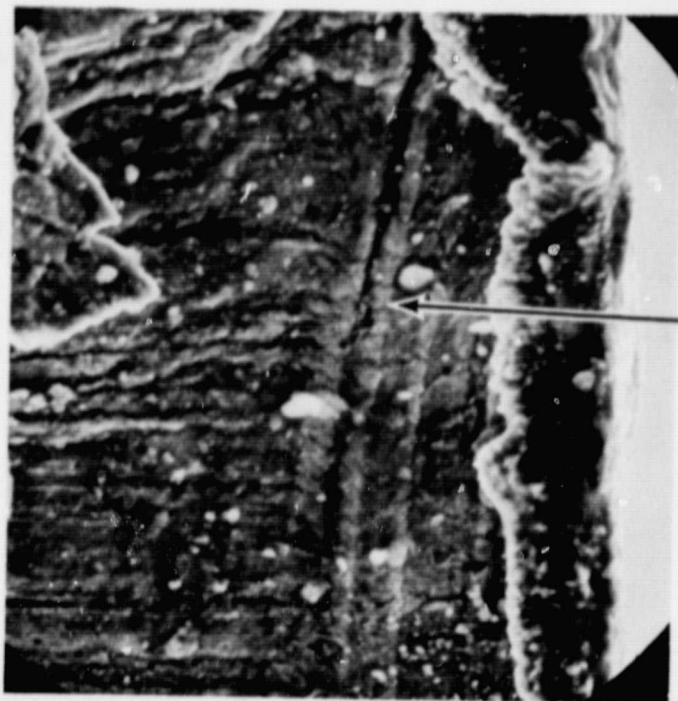


Figure 6 2000X
Fatigue Striations

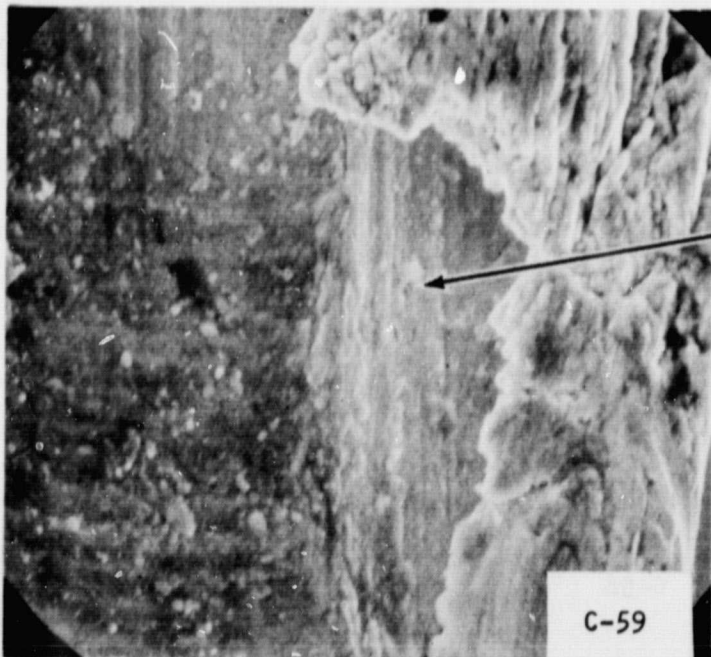
Figure 5 600X
(Area A of Figure 3)



Figure 7 300X
(Area B of Figure 3)



Figure 8 2000X
Fatigue Striations



C-59

TRUCK NO. CAR-386 U-2	MODEL A-926-1	DATE 1-18-81	ODOMETER 6831.8	SERIAL NO. PP 10-14AG
PART FAILURES AND DEFICIENCIES 7830-926-93				
ISSUED TO: DEPT NO. 7830 MR. C. E. Wagner				
PART NAME VEHICLE COMPLETE - GAS TURBINE				
PART NUMBER				
MILES ON PART: 244.4 Miles (Time in Wash. D.C.)				
TYPE OF OPERATION: Vehicle demonstration/display at DOE Headquarters, Washington, D.C.				
BODY STYLE N/A				
DESCRIPTION OF FAILURE OR DEFICIENCY: The vehicle was recalled from Washington to investigate and correct complaints of undershoot, cycling and smoke during cold starts. Warm/hot conditions were trouble free. These symptoms were observed and documented at Chrysler. Minor control system corrections were made without significantly altering the starting characteristics.				
VEHICLE TEST SECTION INSPECTION: (LAB INSPECTION AND REPORT REQUESTED)				
The tank fuel was analyzed because the engine exhaust had a diesel-like odor.				
The analysis is appended and indicates two things:				
1. The sample showed 17% contamination by a well-refined kerosene type solvent.				
2. The fuel was contaminated with lead as stated on the analysis, "if unleaded fuel was added it was contaminated with enough leaded fuel to class it as leaded".				
See Page 2.				
CIMS 422-01-09				
(PLEASE WRITE LABORATORY INSPECTION ON REVERSE SIDE, AND MAIL TO DATA SECTION, DEPARTMENT 5870, PROVING GROUND)				
FORM 220-6735				
CHRYSLER CORPORATION P. P. & D. STAFF				

Fuel was added prior to the vehicle return (during a service call), therefore this fuel sample represents a diluted quantity from the fuel being used when this undershoot problem first occurred. The vehicle is equipped with a legislated unleaded filler neck (small). In addition, a locking gas cap is used. Repeated inquiries by Chrysler personnel as to the use of demonstration fuels always drew a "nothing was added" comment.

Inspection of the combustor and 1st stage wheel showed no obvious unusual deposits.

Subsequent starts with documented MS3900A (unleaded fuel) has shown normal starting characteristics (no undershoots, cycling, or exhaust smoke). Considerable time and effort was expended to resolve this complaint. Eventhough gas turbines have the potential for multi-fuel capabilities, the upgraded engine/control/vehicle system has had no cold/hot start development with alternate fuels of any type. Unleaded gasoline is the specified fuel and should be the only full-time fuel used. However, if other fuels must be demonstrated, Chrysler personnel should be cognizant of its planned use in advance.

Concerns are directed toward the effect of fuel types (e.g., alcohols) on control component elastomers such as the "rubber" inserts used for solenoid valves or check valves. In previous experience with "special" fuels the solenoid elastomer swelled causing it to be inoperative.

The usual Washington source for routine refueling of this car has not had complaints from other customers, which should have resulted if the fuel source was accidentally contaminated with large portions of kerosene or diesel fuel. It is believed that someone added such fuel intentionally. The leaded gasoline, however, could easily have been encountered accidentally without receiving user complaints, since such accidents are being reported regularly by the EPA.

J. V. GROSS

/mab

attachments

cc: WRC-W. I. Chapman
J. Corwin
T. Golec
J. Gross (3)
P. Kerwin - NASA
T. Nogle
R. Padovini
R. Pauley
R. Schleicher
N. Sparks
G. Stecher
E. Trieskey

FUELS AND LUBRICANTS TEST REQUEST

FUELS AND SOLVENTS

DATE 1/23/81 SAMPLE NO. 12381A MATERIAL LAB NO. C-67-2
 DESCRIPTION OF MATERIAL: Turbine fuel NAME OF MATERIAL _____
 M. S. GRP. NO. 5393 VENDOR _____ TRADE NAME OR NO. _____
 OTHER DESCRIPTION: U/L fuel from Turbine car #386 from Washington, D.C. (Turbine Engine cab)
 PURPOSE OF ANALYSIS: Contaminated?

ANALYTICAL RESULTS:

✓ DISTILLATION:

IBP 90°F
 5% 109°
 10% 126°
 15% _____
 20% 153°
 30% 188°
 40% 223°
 50% 247°
 60% 270°
 70% 306°
 80% 366°
 90% 468°
 95% 526°
 DRY POINT 555°
 END POINT _____
 % RECOVERY 96.5
 % RESIDUE 2.6
 % LOSS 0.9

ANILINE POINT _____

MIXED ANILINE POINT _____

✓ UNW. 14,900 mg./100 ml. (9 ml/50 ml)

COLOR _____

CU STRIP CORROSION _____

FLASH POINT _____

KAURI-BUTANOL VALUE _____

OCTANE NO. (MOTOR) _____

OCTANE NO. (RESEARCH) _____

OXIDATION STABILITY _____

RVP _____

✓ SPECIFIC GRAVITY .773 @ 60°

SULFUR _____

✓ TEL LTK = OK for a mixture of leaded & unleaded fuel, 31

✓ ALCOHOL - NIL

COMMENTS ON RESULTS & ACTION REQUIRED:

Leaded regular fuel contaminated with approximately 17% well refined, kerosene-type solvent. No alcohol present. If unleaded fuel was used, it has been contaminated with enough leaded fuel to flag it as leaded.

REQUESTED BY J. GROSS

DEPT. NO. 7830

REPORTED BY S. J.

WORK ORDER NO. CW0 307214

APPROVED BY _____

(GS-5022)

Fill out in duplicate and send to Materials Laboratory with sample

1. Report No. NASA CR-165331		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle SUPPORT SERVICES FOR THE AUTOMOTIVE GAS TURBINE PROJECT - SUMMARY REPORT				5. Report Date April 1981	
				6. Performing Organization Code	
7. Author(s) Chrysler Corporation T. Golec, Editor				8. Performing Organization Report No.	
				10. Work Unit No.	
9. Performing Organization Name and Address Chrysler Corporation P.O. Box 1118 Detroit, MI 48288				11. Contract or Grant No. DEN 3-144	
				13. Type of Report and Period Covered Contractor Report	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, OH 44135				14. Sponsoring Agency Code Rept.# DOE/NASA/0144-81/1	
15. Supplementary Notes Project Officer, Paul T. Kerwin, NASA-Lewis Research Center					
16. Abstract This report summarizes work done between October 1979 and January 1981 by Chrysler Corporation in support of continued use by the Government of Baseline engines and vehicles and Upgraded engines and vehicles delivered by Chrysler to the Government under DOE Contract EY-76-C-02-2749. Support was provided to DOE and NASA in their efforts to inform industry, the public, and Government on the benefits and purpose of the gas turbine programs through demonstrations and exhibits. Tasks were carried out for maintenance, repair, and retrofit of the experimental gas turbine engines being used by NASA in their gas turbine technology programs and in program demonstrations. Limited support testing was conducted at Chrysler in which data were generated on air bearing rotor shaft dynamics, heavy duty variable sheave rubber V-belts, high temperature elastomer regenerator drive mounting and graphite regenerator seal friction characteristics.					
17. Key Words (Suggested by Author(s)) Gas Turbine Engine Air bearing Variable belt drive Regenerator drive			18. Distribution Statement Unclassified-Unlimited		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 148	
				22. Price*	

* For sale by the National Technical Information Service, Springfield, Virginia 22161